UNIVERSITE ABDOU MOUMOUNI

Master Research Program on Climate Change and Energy

MASTER THESIS

ENERGY EFFICIENCY POTENTIAL AND ITS IMPACT ON LONG-TERM ELECTRICITY CONSUMPTION IN URBAN RESIDENTIAL SECTOR: A CASE STUDY OF LOMÉ, TOGO.

Submitted by:

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Abstract

Efficient energy use could help save energy whereas reducing greenhouse gas emissions in emerging countries where less efficient appliances are used. This study attempted to assess the potential of energy efficiency in Lomé's residential sector, capital city of Togo. The impact of efficient energy use on the sector of electricity consumption was analysed with the related carbon dioxide emissions reduction. A system dynamic modelling utilizing Stella software was used to model the electricity consumption. In addition, a survey was conducted in order to assess appliances (lighting, refrigeration, cooling and ventilation) efficiency and to determine if they had been bought as new or used items. Furthermore, the electricity consumption of used and brand new televisions and refrigerator-freezers was monitored. Two different models of Lomé's electricity consumption were built, calibrated and validated with past data of 2000-2016 period. The time span of the models extends from 2000 to 2050.Then, the models were used for the evaluation of three efficient energy policies: 1) Business-As-Usual scenario, 2) New Policies scenario, and 3) Sensitivity scenario. Results revealed a predominantly low efficient appliances percentage in Lomé's housing sector. The model results also showed that the substitution of used electric appliances with new and efficient models may lead Togo to save an important amount of energy and to reduce the related CO_2 emissions. A particular attention was paid to the rebound effect of the energy-efficient measures. Undeniably, if there was any increase in the expected energy savings, this would improve the well-being of the population. The proposed model can be considered as a "*scientific proofs*" for the elaboration of public policy on standard and labelling for household's appliances in emerging countries.

Keys words: *electricity consumption, Lomé, residential sector, energy efficiency, long term, System Dynamics, Stella.*

Acronyms

A	Ampere
ACNEEP	Alliance to Save Energy's Commission on National Energy Efficiency Policy
BR	Birth Rate
BAU	Business-As-Usual
BTI	Binding Tarif Information
CEB	Communaute Electrique du Benin
CEET	Compagnie Energie Electrique du Togo
CIC	Centre Informatique et de Calcul
CIE	Compagnie Ivoirienne d'Electricité
CO_2	Carbon Dioxide
DGDU	Direction de la Gestion du Domaine Universitaire
DR	Death Rate
DYNAMO	DYNAmic Model
ECREE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EE	Energy Efficiency
FBR	Fractional Birth Rate
FDR	Fractional Death Rate
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GNI	Gross National Income
GWh	Giga Watt hour
HFO	Heavy Fuel Oil
IEA	International Energy Agency
INSEED	Institut national des statistiques et des études économiques et démographique
KVA	Kilo Volt Ampere
KWh	kilo Watt hour
LED	Light Emitting Diode.
MW	Mega Watt

NG	Natural Gas
OECD	Organization for Economic Co-operation and Development
RE	Renewable Energy
SCAPE	Stratégie de Croissance Accélérée et de la Promotion de l'Emploi
SD	System Dynamic
SIAME	Société Internationale d'Approvisionnement en Matériel Electrique
SIE	Système d'Information Énergétique
Stella	Structural or System Thinking, Experimental Learning Laboratory with Animation
TCN	Transmission Company of Nigeria
TFP	Technical Financial Partner
TOE	Tone of Oil Equivalent
TWh	Tera Watt hour
USA	United States of America
VRA	Volta River Authority
WB	World Bank
Wh	Watt hour

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Chapter 1

1 INTRODUCTION

1.1 Background of the study

Energy efficiency(EE) is a way of managing and restraining the growth in energy consumption (IEA 2015). It is considered in Organisation for Economic Co-operation and Development (OECD) countries as use of less energy for the same energy service. For emerging countries, it is understood as the use of the same energy to generate more services. In the current context of population growth, environmental concerns, and the increasing energy demand, energy efficiency is playing a key role in a sustainable development. Therefore, it is important to understand the energy demand and estimate the potential of efficient energy use of any sovereign country, especially developing countries. This can stimulate them to implement mechanisms that lead to energy efficiency improvements.

An EE improvement can be when either less energy is used to provide the same level of service or the same energy is used to provide a higher level of services(Ryan & Campbell 2012). It started since energy crises of 1970s, 1980s, and 1990s in USA and evolved until the creation of the Alliance of Saving Energy in 1977: 'Using less. Doing more'(ACNEEP 2013). Since then, a great attention had been paid to renewable energy(RE) and energy efficiency, this because of the benefits that can result from efficiency improvements. As example, without the numerous improvements in energy efficiency carried out since 1973, the U.S. would need about 50% more energy to deliver its current Gross Domestic Product(GDP). Afterwards, in November 1975, the International Energy Agency(IEA) was created to support global collaboration on energy technology in order to secure future energy supplies and reduce their environmental impact. The improvement of EE and the development of low-carbon technologies were, at that time, included too. On the way, EE claimed with RE as the twin pillars for sustainable energy policy by Bill et al., (2007) have been risen up at high priorities in the sustainable energy hierarchy in such a way that EE policies aim at reducing altogether energy consumption and greenhouse gases emissions(REN2021 2012). And on top of all that, EE has been claimed as a key to ensuring a safe, reliable, affordable and sustainable energy system for the future. More, it has been excellently qualified as one energy resource that every country possesses in abundance and the quickest and cheapest way of addressing energy security, environmental and economic challenges (IEA 2017). Consequently, it has become important to find ways of improving EE. For that, Diesendorf proposed the adoption of more efficient technology or an effective production as a way to improve efficient use of energy(Diesendorf 2007). The IEA highlights that proposition through its notification: improved EE in buildings, industrial processes and transportation could reduce the energy needs of the whole world by one third by 2050. This tremendous reduction can help control global greenhouse gases (GHG) emissions inferred as stated by Sophie Hebden (2006). Obviously, developed countries were premiere in adopting EE strategies but Africa is not the least in the area.

Developing countries are having increasingly adopted this policy in their energy planning in order to meet growing energy demand even if much have to be done. For all of them and those in Africa, efficient energy use could help save energy and mitigate their GHG emissions. The continent starts running towards its future energy for sustainable development. According to (Jenny Corry Smith and Matt Jordan n.d.), Africa's awakening is due to the understanding of the possibility for the continent to achieve universal energy access more quickly and cost-effective through wide-scale deployment of highly efficient appliances and equipment. They have also claimed the EE as the cheapest and most abundant way to reduce investments in new power generation, increase grid and service reliability and expand access to electricity in Africa. Furthermore, in case of either access to grid or beyond the grid, EE is seen to be at the heart of a more affordable, more dynamic, more sustainable Africa. In 2013, International Energy Outlook had stated that the energy demand in Africa will increase by over 16 quads, equivalent of 85% from 2010 to 2040. With this regards, Pielli et al., (2016) found that the current context is critical for new power supply and the associated infrastructure. Because of that, the supply could not meet the demand. Only the EE with its role as a least-cost energy resource can reduce the overall demand, decrease the need for expensive peak capacity for the electricity supply to be expanded to meet increasing demand in a timely, low-cost, and sustainable way.

In June 2014, U.S-Africa Energy Ministerial had risen up the importance of increasing the visibility of energy efficiency among Africa Leaders and highlighting African EE successes. From that, Africa must be a venue to showcase successes and lessons learned from African nations and help expand the investment and saving from EE and demand side management. As the future of energy can be decided now, to meet the long-term aim of Africa's energy demand, all Africa's governments are encouraged to put effort towards doubling the access to cleaner, reliable, and efficient electricity, particularly in sub-Saharan where there are some impressive examples.

Investments in sustainable energy, notably in renewable energy and efficiency, have increased in Africa in recent years as stated by United Nations Environment Programme (UNEP) in 2010.

To face the rolling blackouts, the government of Ghana established Africa's first appliance EE standards and labelling program in 2000 that cover compact fluorescent lamps(CFLs), household refrigerators and air conditioners. This program has resulted in estimated peak energy savings of over 120MW. As a result, this EE policy has displaced the need for $105 million (USD) in generation investment and reducing carbon dioxide emissions by over 110,000 tons per year(Katrina Pielli, U.S. Department of Energy; Himesh Dhungel, Doug Mason, Dan Tobin, Millennium Challenge Corporation; and David Gottfried n.d.) and (ECREE 2013). Uganda has had a long program on capacity building on sustainable energy and EE (GEF 2009). They have also tested synergies of parallel infrastructure construction of information and communication technologies and energy which has provided new possibilities for renewable energy supply. Tanzania has taken example on the Ugandan rural electrification programme(Minerals 2013). Namibia has also introduced a set of EE measures to address power shortages at the end of 1990s including efficient light bulbs, efficient cooking and heating devices but also efficiency measures in electricity transmission(UNCTAD 2010) and (Miika Rämä, Esa Pursiheimo, Tomi Lindroos n.d.). Renewable energy and efficiency policies work in parallel, for instance solar water heating in public buildings is now compulsory in Namibia. Mali also has an energy conservation programme since 2010(ADB 2010), which combines policies on renewable energy and EE including lighting and cooking efficiency.

ECOWAS countries are in the process of developing Minimum Energy Performance Standards (MEPS) for lighting, refrigerators and air conditioners. Encouragingly, one can note the creation in 2010 of the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) (ECREEE n.d.). This Centre works to establish an enabling environment for renewable energy and EE investments and markets. Surprisingly, to date the EE's extraordinary potential has not yet been fully exploited by the African policy and energy sector leaders.

Togo is a typical example of such countries where less efficient household appliances are used. Togo, a West African country, is concerned with EE targets because saving energy is important for both its ongoing development and its contribution to reducing GHG emissions. The energy consumed in Togo in 2013 was estimated at 2 173 000 TOEs (0.34 toes per capita) mostly dominated by biomass (65%). But the annual energy consumption (SIE/Togo) of oil and electricity accounted for 29% and 4% in 2012. Precisely the annual energy consumption of the country is mainly distributed between households (64%), transport (24%), market and public services (9%), and industry (3%).

The national electrification rate was approximately 27% in 2012, with 50% in urban areas and 5% in rural areas (SIE/Togo). The latter became 31.46% in 2016 as noted by World Bank. The government of Togo through its national strategy, named 'Stratégie de Croissance Accélérée et de Promotion de L'Emploi' (SCAPE) (2013-2017), expects to boost the national electrification rate to 50% by 2024.

Two companies manage the power system in Togo: 1) La Communauté Electrique du Benin (CEB), whose primary mission is to produce and transport electricity and 2) La Compagnie Energie Electrique du Togo (CEET), which is responsible for the distribution of low and medium voltage. The total power delivered to Togo's network was 275MW in 2013(Ntagungira 2015). The generation facilities are diverse in the country as can be seen in table 1- 1. Contour Global is an independent electricity producer installed in 2010 in the country. The fuels to their generators are natural gas (NG), diesel and a heavy fuel oil (HFO). The plant that operates on HFO, contribute to significantly raise the cost of energy production (Parity is 40 F/kWh NG to 80 F/kWh HFO). Production and distribution infrastructures are aging and may be viewed as the main cause of frequent power shortage and/or outage.

Table 1-1:Generation facilities in 2013 in MW (Ntagungira, 2015)

	Installed	Available	Firm
CEET POWER PLANTS TOGO		128	100
Lome A Thermal Power Plant (Sulzer) Diesel	2X8	7	10
Lome B Thermal Power Plant (CTL site) Diesel	1X14	14	
Kara Thermal Power Plant, Diesel	16	4	
Sokode Thermal Power Plant, Diesel	4	1.5	
Kpime Plant, Turbine	2 X 0.78	1.5	
ContourGlobal Thermal Power Plant, Engine	6 X 16.6	100	90
CEB SOURCES (TOGO AND BENIN)		407	372
Imported TCN (Nigeria)	-	200	200
Imported VRA (Ghana) & CIE (Cote d'Ivoire)	-	102	102
Lome Thermal Power Plant TAGS	2 X 25	40	40
Nangbeto Power Plant (Hydro)	2 X 32.8	65	30
S/total CEB dedicated to Togo (47%)	-	191	175
TOTAL POWER PLANTS AND CEB TOGO		329	275

In fact, most of Togo's electricity is imported (up to 65-70 %) from: 1) Nigeria through the Transmission Company of Nigeria (TCN), 2) Ghana through the Volta River Authority (VRA), and 3) Côte d'Ivoire through La Compagnie Ivorienne d'Electricité (CIE).

The aforementioned percent of electricity imports are illustrated in figure 1-1. Household and industrial electricity consumptions represent respectively 41% and 47%, as shown in Figure 1-2. In addition, the household electricity consumers represent 83.1% of the total subscribers as illustrated in figure 1-3.

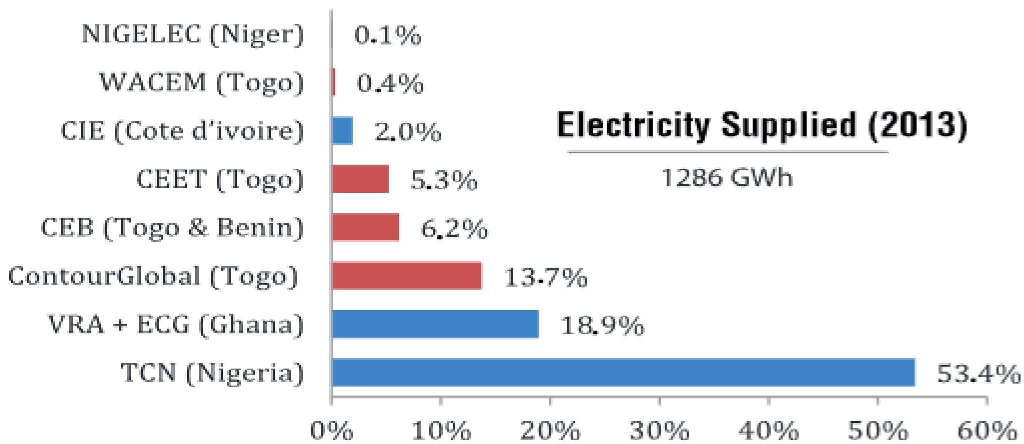
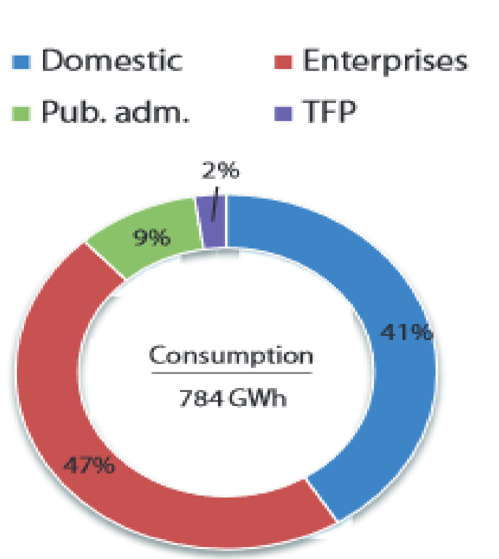


Figure 1-1:Origin of electricity supplied in Togo in 2013 (CEET and 2014 Exploratory Survey



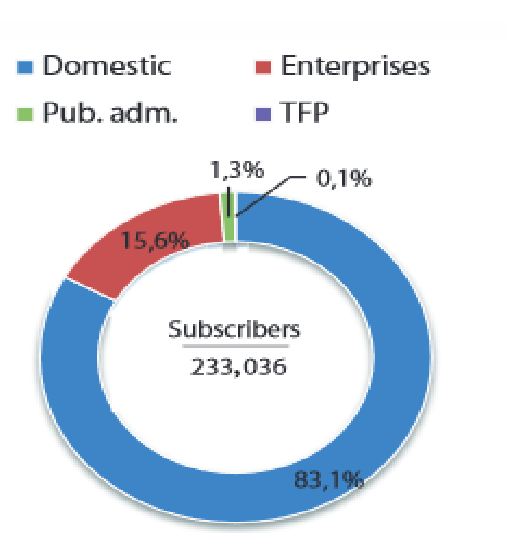


Figure:1-2:Electricity consumption *Figure;1-3:subscriber's distribution*

(Source: CEET and 2014 Exploratory Survey)

1.2 Statement of the research problem

The adoption of renewable energy and energy efficiency(EE) strategies is an important step for any sovereign country to attempt, but the key for real effectiveness resides in their implementation. Unfortunately, these strategies are still in the stage of adoption in most emerging countries, especially those in West Africa.

With an average growth of 8% per year, the electricity demand in Togo will be more than double over the next 10 years. Thus, an additional power need of 200MW is needed to meet the country's ever-growing population and ongoing development.

The future of energy of any nation can be decided in the present time according to the Alliance to Save Energy's Commission on National Energy Efficiency Policy(ACNEEP)(ACNEEP 2013).Taking into account the fact that Nigeria and Ghana are the main electricity providers through CEB, they could potentially reduce their electricity exports due to an increase in their own national energy demand (Ministry of Economy and Finance n.d.). Also from the erlier description of the energy sector of the country, it can be seen that this sector is dominated by the biomass. It is, therefore, important to implement new power generation strategies in Togo. These new measures should especially be directed to clean and renewable energy sources and the country must urgently set up EE measures in various sector, such as, agriculture, industry and mainly the residential which is 64% of the total consumption. Improving EE, wherever possible is vital; it should be set as a country's top priority by ensuring long-term cost savings and reduction of the environmental impacts(IEA 2017).

The city's electrical appliance market is flooded with used and low-efficiency appliances imported from Europe and USA as noted by Samuel et al.,(2016)(Samuel Gyamfi, Felix Amankwah Diawuo, Frank Sika 2016) in developing countries. Unfortunately, Togo is one of the low-income countries in the world with an average Gross National Income(GNI) per capita in 2014 of $530(BTI 2016). In Lomé, because of this low and middle-income status, the number of households that can afford major household appliances is expected to increase, with the possibility of many consumers affording inefficient appliances that will put an additional burden on the electricity demand sector. EE, as stated above, is internationally recognized as a low-cost, readily available resource that could help improve electricity supply. In addition, EE in the context of climate change is an important factor in decoupling the energy demand growth from the economic growth. This study focuses on Lomé residential electricity consumption with an emphasis on the types of appliances that are being used. To date, we are unaware of any such a work that has attempted to comprehensively model the efficient energy consumption in the residential sector of Togo. Therefore, this study attempts to comprehensively model the efficient electric consumption in the residential sector in Lomé using system dynamics modelling.

1.3 Objective of the study

This study seeks to assess the potential of energy efficiency in Lomé residential sector and the corresponding CO_2 reduction by the horizon of 2050 if the proper green policies are adopted. The specific objectives are:

a. Assessment of the socio-economic categories of households and the type of appliances being used in Lomé.
b. Assessment of the current electricity demand in Lomé's residential area and the long-term electricity demand trends (2030 and 2050).
c. Assessment of the total electricity consumption in Lomé and the subsequent CO_2 reduction by 2050 under efficient energy scenarios.

1.4 Research questions

a. What are the energy demand patterns in Lomé's residential sector?
b. How will Lomé's residential electricity consumption trends evolve by the horizon of 2050?
c. What will be the decrease in residential energy consumption and subsequent CO_2 emissions if efficient appliances (lighting, refrigeration, heating, cooling, ventilation, etc.) are implemented by the horizon of 2050?

1.5 The structure of the thesis

The thesis is composed of six chapters. The first chapter presents the general introduction, including the background, the problem statement, the objectives, the research questions, the significance of the study, and the structure of the thesis. Chapter two deals with the literature review. The materials and the methods used are presented in chapter three. Results and discussions are presented in chapter four. Finally, chapter five concludes the thesis with some policy recommendations.

Chapter 2

2 LITERATURE REVIEW

Since the first USA energy crisis of the 1970s, energy supply and demand models are used in order to determine the future energy trends with regards to growing population and economy. This helps nations to take decisions among for efficient usage of energy. Because, the energy security is crucial for economic achievement, and social promotion and happiness. In this order, several studies have been done in the area of residential electricity demand in developed and developing countries utilizing diverse methods of modelling.

2.1 Energy demand planning methods

Traditionally, three energy modelling approaches had been utilized to plan energy system management and the associated gas pollution and greenhouse gas emissions at cities level. These approaches can be classified in: 1) top-down (Meichenbaum n.d.) 2) bottom-up(Müller & Tobias 2000) and 3) hybrid model (Böhringer & Rutherford n.d.).

The top-down approaches are the macroeconomic models developed in the late 1950s with the purpose to help energy suppliers and administrators to decide about the future energy supply. This, to meet the growing energy demand of the rapidly developing of Organisation for Economic Co-operation and Development (OECD) countries. The macroeconomic models are, therefore, used to simulate future energy demand and supply of specific sector including its impacts on economic growth and employment. They encompass input-output models, econometric models, computable general equilibrium models as described by (Herbst et al. 2012). The energy price fluctuations and the financial policies are factors on which they rely muchly. What make them unsuitable for specific technologies development with their related outcomes and investments at a sufficiently detailed level.

The bottom-up approaches are the detailed techno-economic models also known as process-oriented models. They are used to simulate penetration and cost changes of either a new energy technology in a market with a sufficient technical detail. Partial equilibrium models, optimization models, simulation models, multi-agent models are bottom-up models. As disadvantage, they cannot project the economy, the structure and the employment net impacts for society that may result from the new policy.

The hybrid energy system models are the combination of the top-down and bottom-up approaches in order to overcome their weakness and limitations. As stated by (Hourcade et al. 2010), to have a high-quality hybrid model system, one should incorporate at least three properties: (1) technological explicitness, (2) microeconomic realism and (3) macroeconomic completeness. The reason is that top-down approaches provide energy modellers with a high degree of macroeconomic completeness with microeconomic realism. On the other hand, pure bottom-up models offer a high level of technological explicitness and a low level of macroeconomic completeness. The aforementioned approaches use deterministic forecast under assumption and run based on scenarios to predict the evolution of energy system. By doing so, it is difficult to precisely manage the complexities of urban energy system.

As specific model, system dynamic(SD) can be mentioned. SD is an approach used to model and analyse the long-term behaviour of complex systems such as industrial companies, entire cities, entire energy systems, urban energy system, etc. SD was created during the mid-1950s by Pr. Jay W. Forrester of the Massachusetts Institute of Technology(Lane et al. 2011). It helps corporate managers to improve their understanding of industrial processes. Since then System dynamics has been widely used in various socio-economic studies as stated by Radsicki and Taylor (1997).

2.2 Review of previous works

Previous studies have been done on the residential sector's energy demand. Holtedahl et al.,(2004) modelled the demand for residential electricity in Taiwan using an error correction model(Holtedahl & Joutz 2004). They found that the demand for electricity in the sector function of household disposable income, population growth, price of electricity and the degree of urbanisation. Chen et al.,(2009) modelled the residential energy demand in Tokyo utilizing multi-economy data(Top-down and Bottom-up approaches) (Chen & Samuelson n.d.). The results showed that per capita Gross Domestic Product(GDP) impacts energy demand in households. An Autoregressive Distributed Lag (ARDL) approach had been utilized to predict residential and aggregate electricity demand in Namibia (Vita et al. 2005). According to Vita et al, (2005) neither the increase in income does not lead to important increase in households' electricity demand nor the price increase lonely cannot discourage the residential electricity consumption. In 2011, another study was conducted in Nigeria using economic model and system dynamics to model the urban residential energy demand (Kayode et al. 2011). From the results, they had concluded that mostly the power generation and real disposable income affect mostly residential household demand for electricity. In UK in 2012, a research has been conducted on efficient appliances using survey, electricity consumption monitoring and old appliances replacement(Professor Matthew Leach 2012). The objective of the study was to find the contribution of appliance replacement and consumer behaviour on reducing energy usage. After the results analysis, they have found that new appliances offer substantial energy savings with the existing state of technology. The fridge-freezer replacement typically yielded savings of 47% to 66%. Beijing urban energy consumption and CO_2 emission was adequately modelled using system dynamics (Feng et al. 2013). They had found that electricity use per capita was highly correlated with the stock of electrical appliances and GDP. From the above studies, one can notice that households' electricity consumption depends on the income, the price of electricity and the population.

In the field of energy efficiency in urban residential sector, few studies had been conducted in developing countries. The most relevant was conducted in Latin America (Colombia) to comprehensively model residential energy efficiency and management using system dynamics (Dyner et al. 1995).They conclude in saying that SD is proven to be appropriate to support integrated planning and management problems related to EE issues. Samuel et al., (2016) conducted a study on the current energy efficiency status of three household appliances for Ghana(Samuel Gyamfi, Felix Amankwah Diawuo, Frank Sika 2016). The study indicated that due to the energy efficiency measures carried out by the country's government, especially in the replacement of CFLs, made an important electricity savings which offset the national electricity peak demand by 200-240MW while standard and labelling programs made for the air conditioners is expected to provide a demand savings of 250MW. Moreover, it has been stated in the study that this EE is one of the most cost effective means of meeting energy needs. As far as we know, there is no study on the simulation of urban residential energy efficiency in Togo using system dynamics model. This study will attempt to fill in this gap.

Chapter 3

3 MATERIALS AND METHODS

This chapter presents the materials and methods utilized to: 1) attain the objective of the study, and 2) answer the research questions. The structure is as follow: 1) the conceptual framework, 2) the study area, 3) the system dynamics model including the Stella software, 4) the data acquired, 5) the survey, and 6) the experiments.

3.1 Conceptual framework

Figure 3.1 illustrates the conceptual framework of this study. It starts with the study area, then follow the collected data, the model set up with its validation and calibration, the future model simulation based on scenarios and ended with a concise analysis.

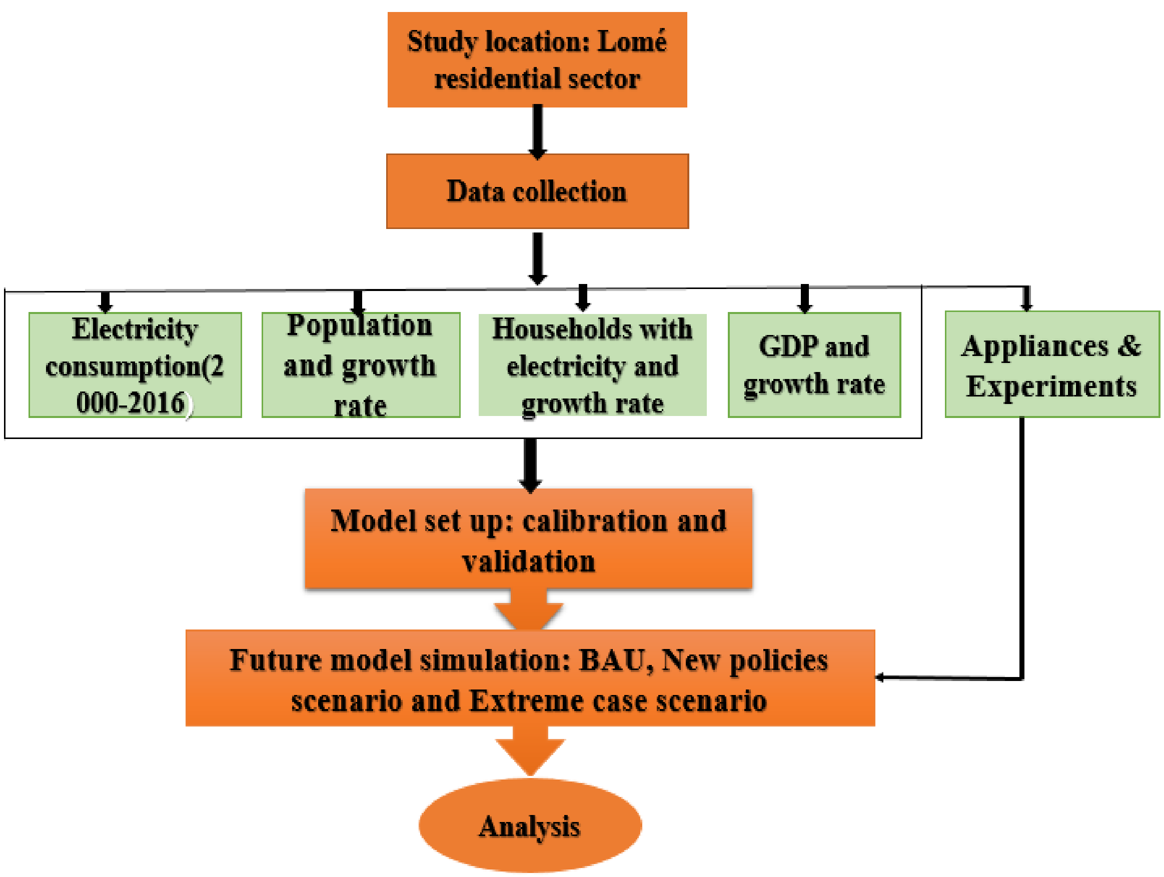


Figure 3-1:Conceptual Framework.

3.2 Study area

The map of the study area, Lomé, is portrayed in figure 3.2. Lomé is situated in the south of Togo (West Africa).

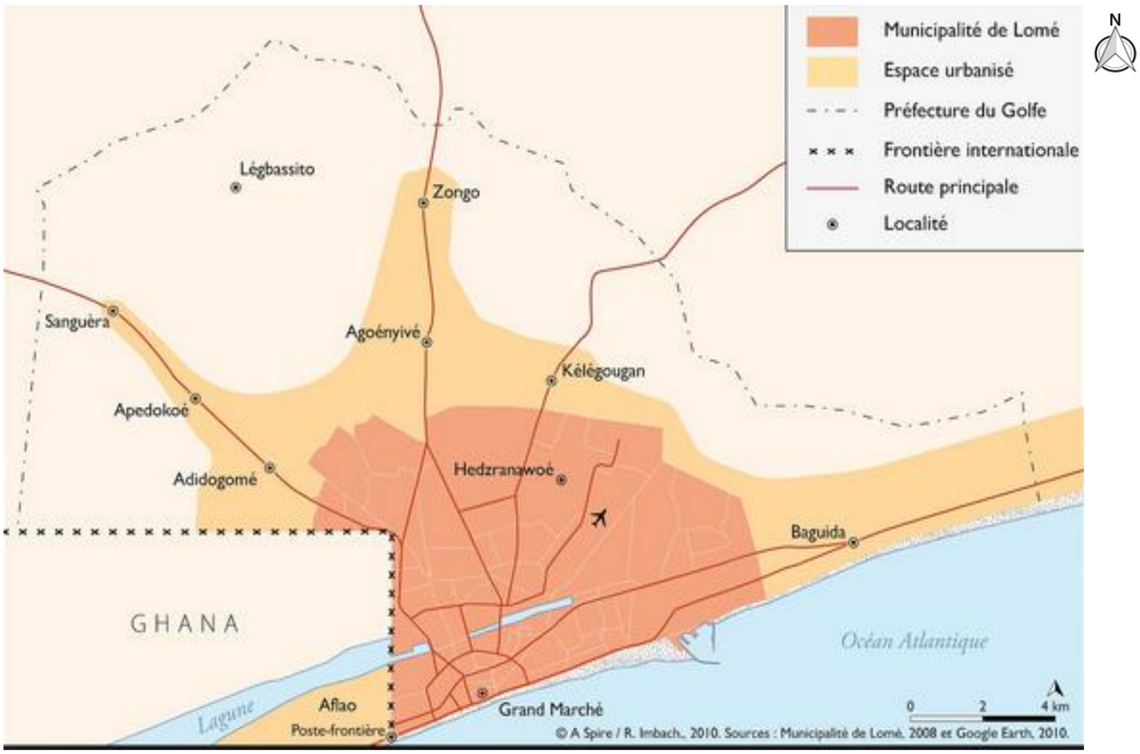


Figure 3-2:Map of the study area(Source: Google map)

Lomé is the capital city of Togo; it is the largest city in the country. It has a population of 1,754 ,589 inhabitants (populations du monde.com, 2012). Located in the Gulf of Guinea (West Africa), Lomé is an administrative and industrial centre. Its occupies an administrative area span over some 333km^2, comprising of 8 administrative subdivisions. It is situated between 6° 08′ 14″ N, 1° 12′ 45″ E. The city has a tropical savanna climate and is relatively dry with an annual average rainfall of 800 – 900 mm and on average 59 rainy days per year. Despite this, it experiences heavy fog most of the year and receives a total of 2330 bright sunshine hours annually. The annual mean temperature is above 27.5 ^oC (81.5 ^oF) but heat is the constant as monthly mean temperatures range from 24.9 ^oC (76.8 ^oF) in July, the least warm month of the year to 29.6 ^oC (85.3 ^oF) in February and in April, the hottest months of the year (www.infoclimat.fr/climat and www.climatestotravel.com/climate/togo).

In 2008, the national annual electric consumption was estimated to be 110 MW. From the latter Lomé's consumption alone accounted for 80 to 85MW, i.e., between 72% to 77.3%. Like other capital cities in emerging countries, Lomé is undergoing rapid transformation, including a rapid population and construction growth, and automobile traffic intensification. Along with the socio-economic development, Lomé has witnessed a significant increase in energy consumption and related carbon dioxide emissions in the last two decades or so. It is worth to mention that Lomé is the most representative town in Togo experiencing rapid urbanization and economic growth, increasing changes in technology, lifestyle, societal transformation, as well as increasing electricity consumption and greenhouse gas (GHG) emissions.

3.3 System dynamics (SD)

3.3.1 Theory of system dynamic

This theory is based on Business Dynamics(John D. Sterman 2000). Systems thinking is the ability to see the world as a complex system in which it is understood that "one cannot just do one thing" and that "everything is connected to everything else"(John D. Sterman 2000). With a holistic worldview, people will then act in consonance with the long-term best interests of the system as a whole, identify the high leverage points in systems, and avoid policy resistance. Indeed, for some, the development of systems thinking is crucial for the survival of humanity. System dynamics is a method to enhance learning in complex systems, such as national energy supply and demand trends. System dynamics is fundamentally interdisciplinary. The main concern is the behaviour of complex systems and the understanding is grounded in the theory of nonlinear dynamics and feedback control developed in mathematics, physics, and engineering. Because these tools are applied to the behaviour of human as well as physical and technical systems, system dynamics draws on cognitive and social psychology, economics, and other social sciences. Therefore, system dynamics is a powerful method to gain useful insight into situations of dynamic complexity and policy resistance. It is increasingly used to design more successful policies in companies and public policy settings.

Modelling is inherently creative and iterative. Styles and approaches may vary from one modeller to another. Yet all successful modellers follow a disciplined process that involves the following activities, as seen in figure 3.3: (1) articulating the problem to be addressed, (2) formulating a dynamic hypothesis or theory about the causes of the problem, (3) formulating a simulation model to test the dynamic hypothesis, (4) testing the model until we are satisfied it is suitable for our purpose, and (5) designing and evaluating policies for improvement. It is important to note that the modelling process is iterative and results of any step can yield insights that lead to revisions in any earlier step indicated by the links in the centre of the diagram.

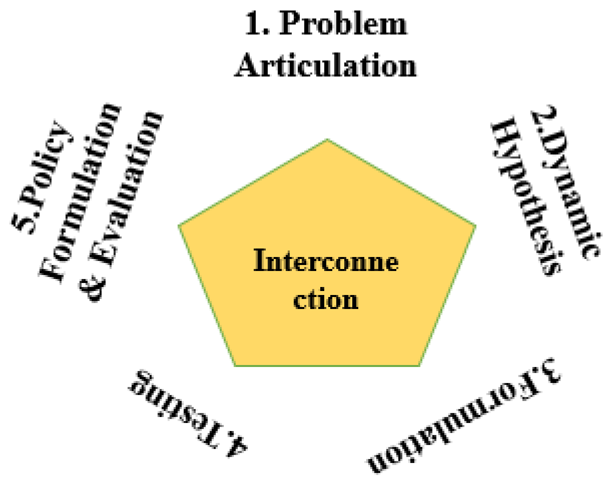


Figure 3-3:Modeling steps or process, adapted from 'System thinking and Modelling for a Complex World' of John D. Sterman(John D. Sterman 2000).

Modelling is not a linear sequence of steps but a feedback process. Models go through constant iteration, continual questioning, testing, and refinement. The initial purpose dictates the boundary and scope of the modelling effort, but what is learned from the process of modelling may feedback to alter our basic understanding of the problem and the purpose of our effort. Iteration can occur from any step to any other step (indicated by the interconnections in the centre of the diagram). In any modelling project one will iterate through these steps many times.

Modelling is also embedded in the dynamics of the system. Effective modelling involves constant iteration between experiments and learning in the virtual world and experiments and learning in the real world.

Most importantly, modelling is embedded in the larger cycle of learning and action constantly taking place in a system as seen in figure 3.4.

Simulation models are informed by our mental models and by information gleaned from the real world. Strategies, structures, and decision rules used in the real world can be represented and tested in the virtual world of the model. The experiments and tests conducted in the model feedback to alter our mental models and lead to the design of new strategies, new structures, and new decision rules. These new policies are then implemented in the real world, and feedback about their effects leads to new insights and further improvements in both our formal and Real World

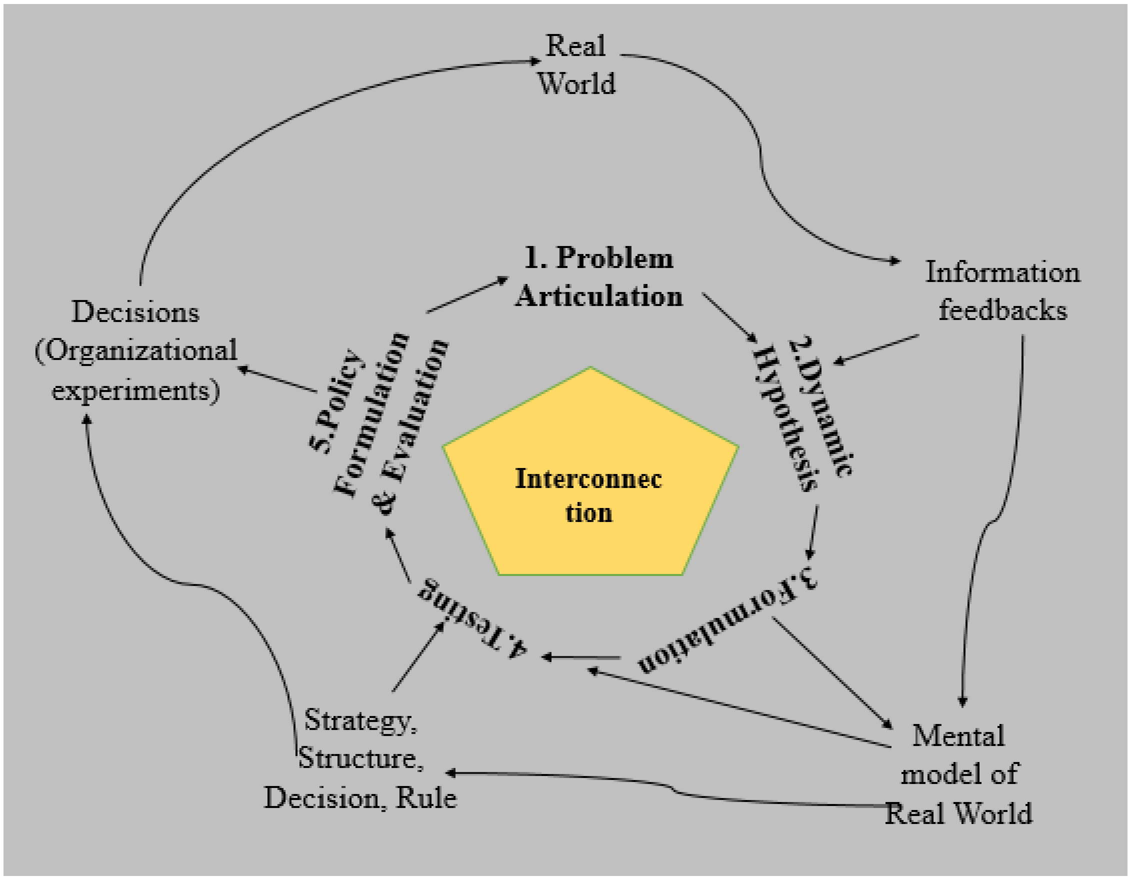


Figure 3-4:Modeling is embedded in the dynamics of the system, adapted from 'System thinking and Modelling for a Complex World' of John D. Sterman(John D. Sterman 2000)

3.3.2 Steps of the modelling process

From System thinking and Modelling for a Complex World of John D. Sterman(John D. Sterman 2000).

3.3.2.1 Problem Articulation: Boundary selection, theme selection

What is the problem? Why is it a problem? Key variables: What are the key variables and concepts we must consider? Time horizon: How far in the future should we consider? How far back in the past lie the roots of the problem?

Dynamic problem definition (reference modes): What is the historical behaviour of the key concepts and variables? What might their behaviour be in the future?

The most important step in modelling is problem articulation. What is the issue people are most concerned with? What problem are they trying to address? What is the real problem, not just the symptom of difficulty? What is the purpose of the model?

A clear purpose is the single most important ingredient for a successful modelling study. Of course, a model with a clear purpose can still be misleading, unwieldy, and difficult to understand. In addition, for a model to be useful, it must address a specific problem and must simplify rather than attempt to mirror an entire system in detail. It deals with a specific policy issue. The usefulness of models lies in the fact that they simplify reality, creating a representation of it we can comprehend. A truly comprehensive model would be just as complex as the system itself and just as inscrutable. It provides the criteria to decide what can be ignored so that only the essential features necessary to fulfil the purpose are left. Mihailo Mestrovic, a developer of early global simulations, captured the impossibility of building models of systems when he said, “No matter how many resources one has, one can envision a complex enough model to render resources insufficient to the task.” (GERHART BRUCKMANN, DONELLA MEADOWS 1982). Of course even models with well-defined purposes can be too large. But without a clear purpose, there is no basis to say “we don’t need to include that” when a member of the client team makes a suggestion. In sum: Always model a problem. Never model a system. Two of the most useful processes are establishing reference modes and explicitly setting the time horizon.

System dynamics modellers seek to characterize the problem dynamically, that is, as a pattern of behaviour, unfolding over time, which shows how the problem arose and how it might evolve in the future. A reference mode should be developed literally as a set of graphs and other descriptive data showing the development of the problem over time. Reference modes (so-called because you refer back to them throughout the modelling process) help to break out of the short- term event-oriented worldview so many people have. To do so it is necessary to identify the time horizon and define those variables and concepts considered as important for understanding the problem and designing policies to solve it.

Time Horizon should extend far enough back in history to show how the problem emerged and describe its symptoms. It should extend far enough into the future to capture the delayed and indirect effects of potential policies. A principal deficiency in our mental models is our tendency to think of cause and effect as local and immediate. But in dynamically complex systems, cause and effect are distant in time and space. Most of the unintended effects of decisions leading to policy resistance involve feedbacks with long delays, far removed from the point of decision or the problem symptom. We have to think about the possible reactions to policies and how long they might take to play out and then increase the time horizon even further. A long time horizon is a critical antidote to the event-oriented worldview so crippling to our ability to identify patterns of behaviour and the feedback structures generating them. The choice of time horizon dramatically influences our perception of the problem(John D. Sterman 2000).

3.3.2.2 Formulation of Dynamic Hypothesis.

Once the problem has been identified and characterized over an appropriate time horizon, modellers must begin to develop a theory. The hypothesis is dynamic because it must provide an explanation of the dynamics characterizing the problem in terms of the underlying feedback and stock and flow structure of the system. It is a hypothesis because it is always provisional, subject to revision or abandonment as we learn from the modelling process and from the real world. A dynamic hypothesis is a working theory of how the problem arose.

Initial hypothesis generation: What are current theories of the problematic behaviour?

Endogenous focus: Formulate a dynamic hypothesis that explains the dynamics as endogenous consequences of the feedback structure.

Mapping: Develop maps of causal structure based on initial hypotheses, key variables, reference modes, and other available data, using tools such as Model boundary diagrams, Subsystem diagrams, Causal loop diagrams, Stock and flow maps, Policy structure diagrams, Other facilitation tools. Causal loop diagrams emphasize the feedback structure of a system. Stock and flow diagrams emphasize their underlying physical structure. Stocks and flows track accumulations of material, money, and information as they move through a system. Stocks include inventories of product, populations, and financial accounts such as debt, book value, and cash. Flows are the rates of increase or decrease in stocks, such as production and shipments, births and deaths, borrowing and repayment, investment and depreciation, and receipts and expenditures. Stocks characterize the state of the system and generate the in- formation upon which decisions are based. The decisions then alter the rates of flow, altering the stocks and closing the feedback loops in the system.

In practice, discussion of the problem and theories about the causes of the problem are jumbled together in conversation with stakeholders. System dynamics, one focuses on endogenous variables more than exogenous variables in the models(John D. Sterman 2000).

3.3.2.3 Formulation of a Simulation Model.

Once we've developed an initial dynamic hypothesis, model boundary, and conceptual model, we have to test them. Sometimes we can test the dynamic hypothesis directly through data collection or experiments in the real system. At this step we specify the model's structure and set up the decision rules. In addition, we estimate the parameters involved in the model. We then must move from the conceptual realm of diagrams to a fully specified formal model, complete with equations, parameters, and initial conditions. Tests for consistency with the purpose and boundary. Modelling is not a one-shot activity that yields The Answer, but an ongoing process of continual cycling between the virtual world of the model and the real world(John D. Sterman 2000).

3.3.2.4 Testing

Comparison to reference modes: Does the model reproduce the problem behaviour adequately for your purpose?

Robustness under extreme conditions: Does the model behave realistically when stressed by extreme conditions?

Sensitivity: How does the model behave given uncertainty in parameters, initial conditions, model boundary, and aggregation?

Testing begins as soon as we write the first equation. Part of testing, of course, is comparing the simulated behaviour of the model to the actual behaviour of the system. But testing involves far more than the replication of historical behaviour. Every variable must correspond to a meaningful concept in the real world. Every equation must be checked for dimensional consistency. The sensitivity of model behaviour and policy recommendations must be assessed in light of the uncertainty in assumptions, both parametric and structural. Models must be tested under extreme conditions, conditions that may never have been observed in the real. Extreme conditions tests, along with other tests of model behaviour, are critical tools to discover the flaws in the built model and set the stage for improved understanding(John D. Sterman 2000).

3.3.2.5 Policy Design and Evaluation

Scenario specification: What environmental conditions might arise?

Policy design: What new decision rules, strategies, and structures might be tried in the real world? How can they be represented in the model? “What if. . .” analysis: What are the effects of the policies?

Sensitivity analysis: How robust are the policy recommendations under different scenarios and given uncertainties?

Interactions of policies: Do the policies interact? Are there synergies or compensatory responses? Policy design is much more than changing the values of parameters. Policy design includes the creation of entirely new strategies, structures, and decision rules. Since the feedback structure of a system determines its dynamics, most of the time high leverage policies will involve changing the dominant feedback loops by redesigning the stock and flow structure, eliminating time delays, changing the flow and quality of information available at key decision points, or fundamentally reinventing the decision processes of the actors in the system. The robustness of policies and their sensitivity to uncertainties in model parameters and structure must be assessed, including their performance under a wide range of alternative scenarios. The interactions of different policies must also be considered: Because real systems are highly nonlinear, the impact of combination policies is usually not the sum of their impacts alone. Often policies interfere with one another; sometimes they reinforce one another and generate substantial synergies(John D. Sterman 2000).

3.4 Stella Software

While working at the Massachusetts Institute of Technology in the 1960s, Jay Wright Forrester developed the earliest understanding of system dynamics which he argued could only be understood using models. In 1984, Dartmouth College systems science professor Barry Richmond founded High Performance Systems. With financial support of Analog Devices, Inc. and technical support from Apple Computer, he developed STELLA at his company(Lebanon n.d.). He presented the prototype for the visual programming language in 1985 at the System Dynamics Society's annual conference in a paper entitled "STELLA: Software for Bringing System Dynamics to the Other 98%"(Richmond 1985).

Steve Peterson, a colleague of Richmond's, reflected after his death in 2002 that Richmond held the belief that modelling was a tool everyone should be using and that notion was reflected in Richmond's work. He quoted a 1994 paper in which Richmond described STELLA as "quite unique, quite powerful, and quite broadly useful as a way of thinking and or learning. It's also capable of being quite transparent–leveraging the way we learn biology, manage our businesses, or run our personal lives".

STELLA's approach to modelling systems shares some similarities with a precursor, the DYNAMO simulation language. DYNAMO explicitly defined "stocks" (reservoirs) and "flows" (inputs and outputs) as key variables in a system, a vocabulary which STELLA shares). Within STELLA, users are presented with a graphical user interface in which they may create graphical models of a system using four fundamentals building blocks: stocks, flows(inflow/input and outflow/output), converters, and connectors (Martin 1997).

Figure 3.5 is a simple STELLA model of population of Lomé; stocks are represented as rectangles, flows as pipes to (inflow or input)/from the stock (outflow or output), converters as the circles, and connectors as the curved lines with arrows. Users are able to input values for stocks, flows, and converters.

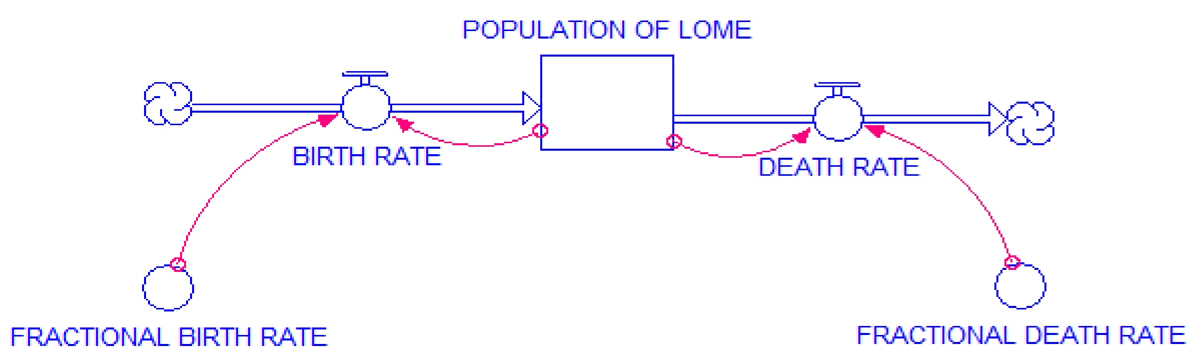


Figure 3-5:A simple Stella model, adapted from (Richmond 1985)

Stocks variables also called state variables indicate the status of the system through time and they represent stocks. Stocks are so accumulations, collecting whatever flows into them and/or net of whatever flows out of them.

Flow variables or control variables are the ones that directly change the stocks; they can increase(Birth) or decrease(Death) the stocks through. Connectors, as its name suggests, connect model elements. There are for two distinct types of connector: the action connector and the information connector. Action connectors are signified by a solid, directed wire. Information connectors are signified by a dashed wire.

Converters serve a utilitarian role in the software. They hold values for constants, defines external inputs to the model, calculates algebraic relationships, and serves as the repository for graphical functions. In summary, they convey transforming variables.

Figure B.1 presents the graphical representation of the so called building blocks. Figure B.2, in other hand highlights the function of the aforementioned blocks.

STELLA has been used in academia as a teaching tool and has been utilized in a variety of research and business applications. The program has received positive reviews, being praised in particular for its ease of use and low cost(Wikipedia n.d.).

The software produces finite difference equations that describe the graphical model and allows users to select a numerical analysis method to apply to the system, either the Euler method or various Runge–Kutta methods (either second or fourth order). Before running a model, users may also specify a time step and runtime for the simulation. STELLA can output data in graphical or tabular forms(Wikipedia n.d.)

STELLA runs one window at a time meaning that only one model can be run at any given moment. The program's native file formats are denoted either by an .stm, .stmx, .itm, or .itmx filename extension.

3.5 Lomé's electricity consumption system dynamic model

Lomé's electricity consumption in residential sector is a dynamic system due to the fact that many factors interact within the system. The factors are variables such as population, GDP, appliances, number of households and per capita electricity consumption in Lomé city.

To build a better model, I considered past data on Lomé's electricity consumption in residential sector from 2000 to 2016. The purpose was to use these historical data to appreciate and validate the model. Two horizons had been taken into consideration: near future, 2030 and far future, 2050. According to the objectives of the study, two models had been built. One model has as principal variables population, GDP and per capita electricity consumption: Lomé Electricity Consumption System Dynamic with GDP and Population growth (LECSDGPG). The second model's principal variables are population, number of households having access to electricity and per capita electricity consumption: Lomé Electricity Consumption System Dynamic with Population and

Households having access to Electricity (LECSDPHAE). We were not able to get precisely the number of households having access to electricity and also the electricity consumption in Lomé's residential sector, so we had estimated these data using two assumptions built basing on annual report of CCET from 2012 to 2015; and 2014 exploratory survey in *Underlying Issue of Electricity Access in Togo.* (Ntagungira Carpophore, 2015):

- 83.64% of clients of low-tension (BT) in Lomé represent the number of households having access to electricity.
- 80% of the electricity consumption of low-tension (BT) is consumed in households in Lomé.

In CEET, except industries and big enterprises, the remain clients are under low-tension or voltage (from 2.2 KVA to 13.2 KVA with corresponding intensity 10A to 60A)

3.5.1 Models

Lomé electricity consumption system dynamic with GDP and population growth (LECSDGPG) model and Lomé electricity consumption system dynamic with population and households having access to electricity (LECSDPHAE) model are presented below followed by the mathematical formulations that show the equations behind the models. These equations help to understand deeply the theory that is hided.

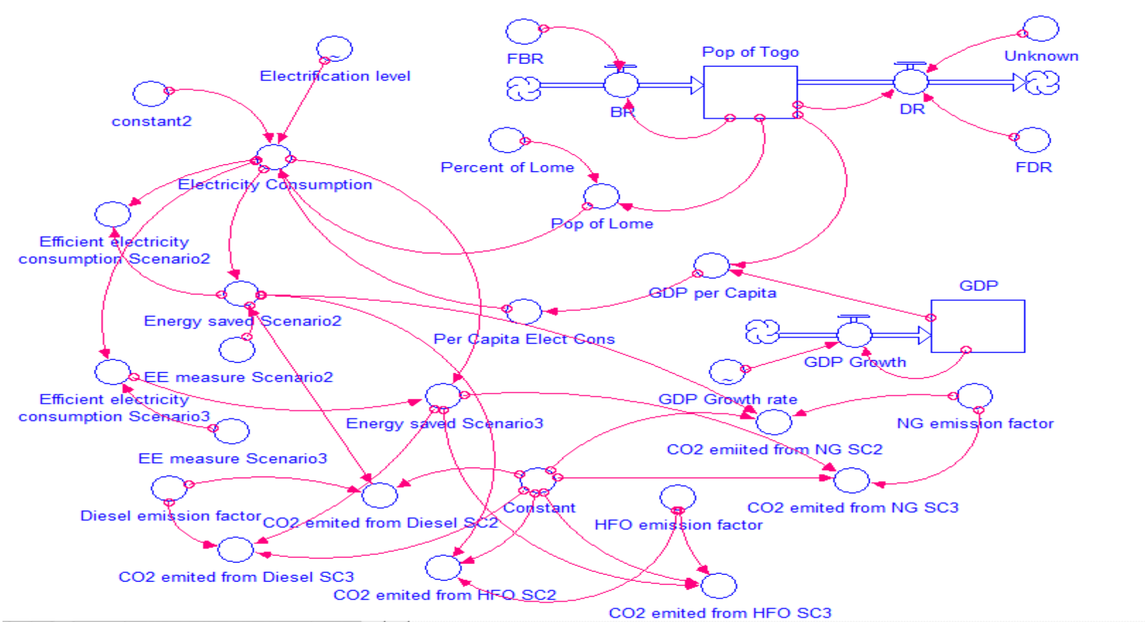


Figure 3-6:Model of LECSDGPG

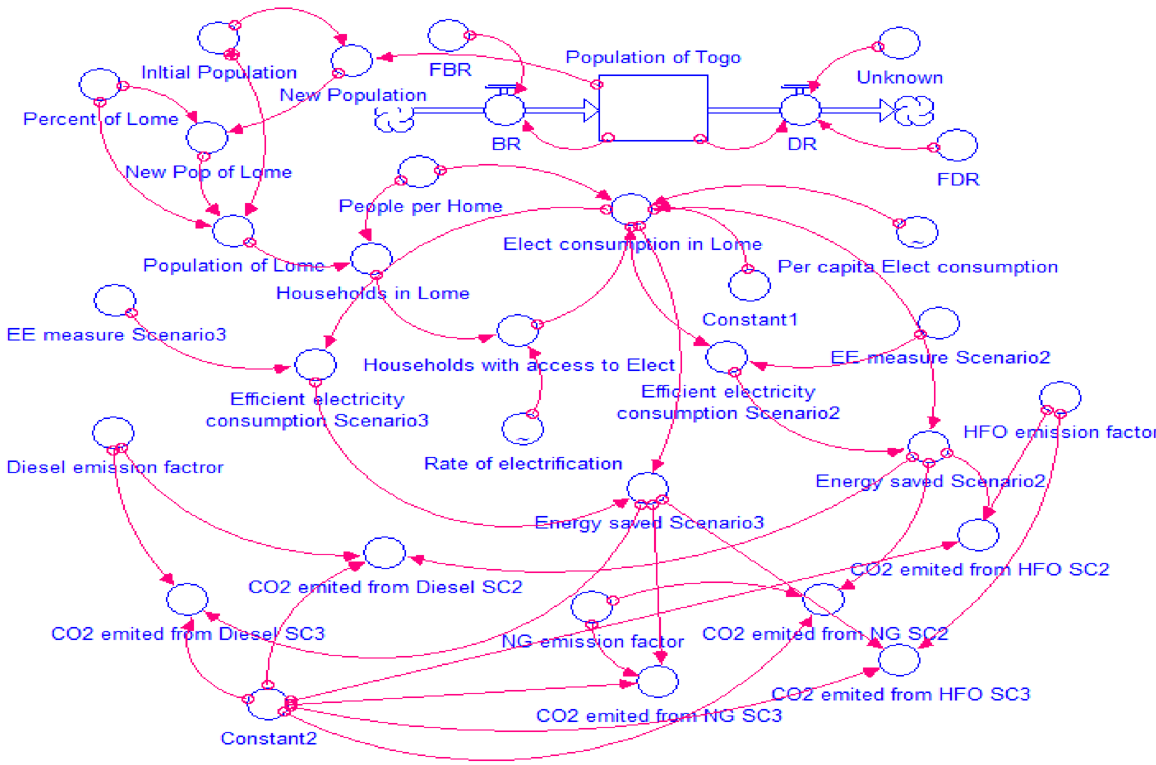


Figure 3-7:Model of LECSDPHE

3.5.2 Mathematical formulations

The mathematical functions to the long term electricity consumption in Lomé's residential sector are presented in this section.

3.5.2.1 Mathematical formulations of LECSDGPG model

- **Gross Domestic Product (GDP)**

The inflow to the GDP is the GDP growth. Therefore, the GDP based on the above mentioned inflow at instant (t) can be estimated using (3.1).

The equation (3.3) expresses how to compute the GDP growth knowing the rate at which GDP is growing each year. Concerning GDP growth rate, it is an exponential function expressed in equation (3.4)

$$GDP(t) = GDP(t - dt) + (GDP\_Growth) * dt \qquad (3.1)$$

Where,

GDP(t) is the GDP at time, 't'

GDP(t-dt) is the GDP at previous time step,

GDP_Growth is the increase of the GDP each year while '*INIT GDP'* of Togo is the initial GDP in 2000, equation (2).

INIT GDP = 1330000000 (3.2)

*GDP_Growth = GDP*GDP_Growth_rate* (3.3)

GDP_Growth_rate = GRAPH(TIME) (3.4):

(2000, 0.0294), (2005, 0.0339), (2010, 0.0378), (2015, 0.0409), (2020, 0.0482), (2025, 0.0513), (2030, 0.0586), (2035, 0.0616), (2040, 0.0665), (2045, 0.069), (2050, 0.07)

- **Population**

The inflows to the population consist of births while deaths are considered as the outflows, i.e. the decreasing or balancing factor from the "population". Therefore, based on the above mentioned dynamics at any instant (t) the population can be estimated utilizing (3.4). The equation (3.5) points out the initial population of Togo in 2000.

Pop_of_Togo(t) = Pop_of_Togo (t - dt) + (BR - DR) * dt (3.5)

INIT Pop_of_Togo = 5400000 (3.6)

BR = Pop_of_Togo/1000*FBR (3.7)

DR = Pop_of_Togo/1000*FDR/Unknown (3.8)

FBR = 39.2 (3.9)

FDR = 10.6 (3.10)

Percent_of_Lome = 0.25 (3.11)

Pop_of_Lome = Pop_of_Togo*Percent_of_Lome (3.12)

Unknown = 1 (3.13)

Where,

Pop_of_Togo(t) is the population of Togo at time, 't',

Pop_of_Togo (t - dt) is the population at previous time step,

BR is the number of births in time, dt, and

DR is the number of death in time, dt.

FBR and FDR are respectively the fractional rates of birth and death expressed in percentage while the Unknown is any eventual event that could increase the number of death I the country. The population of Lomé is approximatively 25% of the population of the country and the equation (3.12) is the formula thereby Lomé’s population can be estimated.

- **Lomé’s households Electricity consumption**

Under this model, the electricity consumption is population of Lomé times per capita electricity consumption times the electrification of rate of Lomé expressed in equation (3.14).

Electricity_Consumption = Pop_of_Lome*Per_Capita_Elect_Cons*Electrification_Level (3.14)

Where,

Per capita electricity consumption is a linear function (source) for simplicity of GDP per capita shown in equation (3.17). On the other hand, GDP per capita is GDP over the population as given in equation (3.16) but the electrification level is an exponential function shown in equation (3.18).

constant2 = 1.45 (3.15)

GDP_per_Capita = GDP/Pop_of_Togo (3.16)

Per_Capita_Elect_Cons = GDP_per_Capita*0.4279+26.2808 (3.17)

Electrification_level = GRAPH(TIME) (3.18)

(2000, 0.405), (2005, 0.548), (2010, 0.597), (2015, 0.772), (2020, 0.932), (2025, 0.981), (2030, 0.994), (2035, 0.984), (2040, 0.987), (2045, 0.984), (2050, 1.00)

- **Electricity saved**

The economy of electricity is the consequence of energy efficiency policies scenarios. Under the two types of efficiency scenarios, the electricity saved is given by electricity consumption times energy efficiency ratio over 100 as expressed in equations (3.19) and (3.20) or can also be estimated as electricity consumption minus efficient energy consumption scenario.

Energy_saved_Scenario2 = Electricity_Consumption*EE_measure_Scenario2/100 (3.19)

Energy_saved_Scenario3 = Electricity_Consumption*EE_measure_Scenario3/100 (3.20)

Efficient_electricity_consumption_Scenario2 = Electricity_Consumption-Energy_saved_Scenario2 (3.21)

Efficient_electricity_consumption_Scenario3 = Electricity_Consumption-Electricity_Consumption*EE_measure_Scenario3/100 (3.22)

EE_measure_Scenario2(%) = 4.4 (3.23)

EE_measure_Scenario3(%) = 28.2 (3.24)

- **Carbon dioxide emissions reduction**

Emissions are one of the products of combustions, especially stationary combustion in case of this study. Equations (3.24) to (3.29) are formula used in the built models and scenarios to estimate the emissions related to the electricity production if diesel, natural gas and heavy fuel oil are used as combustibles (equations below).

CO2_emiited_from_NG_SC2 = Energy_saved_Scenario2/Constant*NG_emission_factor (3.24)

CO2_emited_from_Diesel_SC2 = Energy_saved_Scenario2/Constant*Diesel_emission_factor (3.25)

CO2_emited_from_Diesel_SC3 = Energy_saved_Scenario3/Constant*Diesel_emission_factor (3.26)

CO2_emited_from_HFO_SC2 = Energy_saved_Scenario2/Constant*HFO_emission_factor (3.27)

CO2_emited_from_HFO_SC3 = Energy_saved_Scenario3/Constant*HFO_emission_factor (3.28)

CO2_emited_from_NG_SC3 = Energy_saved_Scenario3/Constant*NG_emission_factor (3.29)

Constant = 277777.78 (3.30)

Diesel_emission_factor = 74.1 (3.31)

HFO_emission_factor = 77.4 (3.32)

NG_emission_factor = 56.1 (3.33)

These equations derived from TIER 1 approach. A method used by IEA to estimate greenhouse gases emissions from stationary combustion which can be expressed as:

Emissions (GHGs, Fuel) = Fuel consumption*Emission factor (GHGs, Fuel) (3.34).

Where,

Fuel consumption is the amount of fuel combusted, but in this study it signifies the amount of fuel that could be reduced in context of energy efficiency policies promotion.

Emission factor is a default emission factor of carbon content.

Equation (3.30) is a constant giving the conversion from Terajoules (Tj) to Kilowatt-hour(kWh) and CO2 emission factor in tones/Tj related to above mentioned fuel are presented in equations (3.31) to (3.33).

3.5.2.2 Mathematical formulations of LECSDPHAE model

- **Population**

Population in equation (3.35) has the same inflow and outflows as described in equation (3.5) and the equations (3.36) to (3.40) are the same as in equations (3.6) to (3.10).

Population_of_Togo(t) = Population_of_Togo (t - dt) + (BR - DR) * dt (3.35)

INIT Population_of_Togo = 4874735 (3.36)

BR = Population_of_Togo/1000*FBR (3.37)

DR = (Population_of_Togo/1000) *FDR/Unknown (3.38)

FBR = 39.2 (3.39)

FDR = 10.6 (3.40)

Unknown = 1 (3.41)

- **New population and population of Lomé**

It is very imperative to not just accurately model the existing population, but also to be able to model the new population during the upcoming years. This will enable us to project, as accurately as possible, the future electricity consumption in Lomé. This new population is estimated through equations (3.42) and (3.43). Equation (3.45) is the formula to estimate the population of Lomé and equation (3.43) is the percent of the population of as state earlier.

New_Population = Population_of_Togo-InItial_Population (3.42)

New_Pop_of_Lome = New_Population*Percent_of_Lome (3.43)

Percent_of_Lome = 0.25 (3.44)

Population_of_Lome = InItial_Population*Percent_of_Lome+New_Pop_of_Lome (3.45).

- **Households in Lomé**

The number of households in Lomé is expressed as the population of Lomé over the number of people per household, equation (3.46), which is 5 in this study, equation (3.47). People per household in Togo is estimated according to the World Bank.

Households_in_Lome = Population_of_Lome/People_per_Home (3.46), People_per_Home = 5 (3.47).

- **Electricity consumption in Lomé**

Under this model, the electricity consumption in Lomé is per capita electricity consumption times people per household times households having access to electricity times a constant, equation (3.48). Households with access to electricity is expressed as households in Lomé times the rate of electrification equation (3.49). This because, the company in charge of energy in Togo estimates the rate electrification level as the number of households having access to electricity over the total number of households. The constant in equation (3.50) had been introduced as a coefficient of correction. Per capita electricity consumption in Togo is estimated according to World Bank and it is in this study expresses as exponential function, this for the purpose of accuracy showing the possible increase due to the economy growth, equation (3.51). For the rate of electrification, it is increasing due to the country energy policies targets to improve and widen the access to electricity in the country and especially in Town, equation (3.52).

Electricity_consumption_in_Lome = Per_capita_Elect_consumption*People_per_Home*Households_with_access_to_Elect*Constant1 (3.48)

Households_with_access_to_Elect = Households_in_Lome*Rate_of_electrification (3.49)

Constant1 = 1e+1/5 (3.50)

Per_capita_Elect_consumption = GRAPH(TIME) (3.51)

(2000, 121), (2005, 128), (2010, 146), (2015, 160), (2020, 169), (2025, 192), (2030, 199), (2035, 211), (2040, 225), (2045, 240), (2050, 250)

Rate_of_electrification = GRAPH(TIME) (52)

(2000, 0.359), (2005, 0.405), (2010, 0.468), (2015, 0.545), (2020, 0.597), (2025, 0.661), (2030, 0.727), (2035, 0.778), (2040, 0.87), (2045, 0.942), (2050, 1.00)

- **Electricity saved**

The economy of electricity analysis is the same under this model as described earlier in the LECSDGPG model.

EE_measure_Scenario2(%) = 4.4 (3.53)

EE_measure_Scenario3(%) = 28.2 (3.54)

Efficient_electricity_consumption_Scenario2 = Elect_consumption_in_Lome-Elect_consumption_in_Lome*EE_measure_Scenario2/100 (3.55)

Efficient_electricity_consumption_Scenario3 = Elect_consumption_in_Lome-Elect_consumption_in_Lome*EE_measure_Scenario3/100 (3.56)

Energy_saved_Scenario2 = Elect_consumption_in_Lome-Efficient_electricity_consumption_Scenario2 (3.57)

Energy_saved_Scenario3 = Elect_consumption_in_Lome-Efficient_electricity_consumption_Scenario3 (3.58)

- **Carbon dioxide emissions reduction**

The interpretation of this part is the same as in the LECSDGPGP model.

CO2_emited_from_Diesel_SC2 = Energy_saved_Scenario2/Constant2*Diesel_emission_factror (3.59)

CO2_emited_from_Diesel_SC3 = Energy_saved_Scenario3/Constant2*Diesel_emission_factror (3.60)

CO2_emited_from_HFO_SC2 = Energy_saved_Scenario2/Constant2*HFO_emission_factor (3.61)

CO2_emited_from_HFO_SC3 = Energy_saved_Scenario3/Constant2*HFO_emission_factor (3.62)

CO2_emited_from_NG_SC2 = Energy_saved_Scenario2/Constant2*NG_emission_factor (3.63)

CO2_emited_from_NG_SC3 = Energy_saved_Scenario3/Constant2*NG_emission_factor (3.64)

Constant2 = 277777.78 (3.65)

Diesel_emission_factror = 74.100 (3.66)

HFO_emission_factor = 77.400 (3.67)

NG_emission_factor = 56.100 (3.68)

3.6 Data acquisition

Data are core material for any research. Acquiring them require sources. This section presents the data acquired for the study and their various sources. Are presented the historical number of electrified households per year in Lomé, historical electricity consumption of Lomé's residential sector. It is then presented the population of Togo, the birth and death rates and the per capita electricity consumption in Togo. The sources of the abovementioned data are also presented.

3.6.1 Historical number of electrified households in Lomé

The number of electrified households per year in Lomé is same as the total yearly number of clients supplied by the utility company (CEET). The electrified households per year was collected from the abovementioned electricity company for the year 2000 to 2016 (Table A.2). Electrified households of the capital progresses due to rapid population growth, unprecedented urbanization growth and increasing economic growth. The clients of CEET in Lomé represents 65.50% of the company's total clients in 2016. They were used to validate the residential electricity consumption model of Lomé in this system dynamic model.

3.6.2 Historical data of Lomé's electricity consumption, residential sector

The residential electricity consumption data from the year 2000 to 2016 were collected from the company in charge of energy distribution CEET (Table A.1). The data were then used in the Stella software in order to validate Lomé's residential electricity consumption. According to the 2016 annual report of CEET, the rate of electrification of Lomé in this same year was 92.47%, while the electrification rate of the whole country was 35.81%. The number of houses with access to electricity in Lomé accounts for 65.50% in the country, in 2016 according to the aforementioned company in charge of energy.

3.6.3 Population, fractional birth rate, fractional death rate and electricity consumption per capita data

These data were collected from the Institut national des Statistiques et des Études Économiques et Démographique (INSEED) and from Word Bank. The fractional birth and death rates of Togo are estimated respectively at $32.9^{0}/_{00}$ and $10.6^{0}/_{00}$ according to 4e Rescencement General de la Population et de l'Habitat done in 2010 by INSEED. As it can be seen, the time span of the model extends from 2000 to 2050, therefore, the fractional birth rate $39.3^{0}/_{00}$ of 2000 (Factfish 2016) was chosen. The habitants per household is estimated at 5, according to World Bank in 2012. The electricity consumption per capita was estimated according to the data of Word Bank.

3.7 Survey

There is no available data on appliances used in Lomé residential sector presenting their brands, their nominal powers, the time of usage per day, and if they were bought new or used items. The survey was formulated and conducted on a random representative sample of 242 households in Lomé having access to electricity to collect the necessary information on the appliances as illustrated in case summary (table 3.1). The questionnaire with full details can be found in appendix c.

Table 3-1: Case summary

Cases Summary						
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
$Q1	242	100.00%	0	0.00%	242	100.00%

a. Group

3.8 Experiments

There is no database on the electricity consumption of the second-hand appliances in comparison to new brands'. Experiments had been conducted for one month on three type of appliances: TV, refrigerator and freezers. For each type, new brand one and second-hand or old one had been considered. The experiment on TV, refrigerators and freezers were conducted in households. An electricity meter, *SIAME*, was used as a device to measure the electricity consumption of appliances for a duration of one month in average. Figures below present the different experiments.

3.8.1 Experimental montage

The different experiments conducted are presented in the figures 3.10 to 3.13 that follow.

Characteristics:

Voltage: 220-240V

Frequency: 50Hz

Rated power: 128-152W

Figure 3-8:Installation the refrigerator-freezer SHARP new brand

Characteristics:

Voltage: 220-240V

Frequency: 50Hz

Rated power: (180W)

Figure 3-9:Installation of the used refrigerator-freezer(unknown)

Characteristics:

Voltage: 230V

Frequency: 50Hz

Rated power: 55W

Figure 3-10:Installation of the used television Mivar 20P1

Characteristics:

Voltage:110 - 240V

Frequency: 50/60Hz

Rated power: 45 - 180W

Figure 3-11:Installation of relatively new TV Sharp

3.9 Scenarios

3.9.1 Scenario 1: Business-As-Usual

Any new energy efficiency policy has not been introduced.

3.9.2 Scenario 2: Some households are using efficient appliances

No more incandescent bulbs, second-hand TVs, second-hand refrigerators and second-hand freezers in Lomé's households. Incandescent bulbs are replaced by led bulbs and lamps for usage should follow some characteristics concerning their power (Table 3.2), and second-hand TVs, refrigerators and freezers are replaced by new brand one (tables 3.3 to 3.5).

To calculate the yearly electricity consumption, the formula *P*H*365/1000* was used where P represents the mean power of the appliance in watt, H represents the number of hours of utilization of the appliance per day, 365 is the number of days in a year and the division per 1000 represents the conversion from Wh to kWh.

Table 3-2: Usage of lamps without incandescent bulbs

Lamps	Neon bulbs	Fluorescent bulbs	led bulbs	New lamps(Led bulbs)
Number	130	186	43	8
Daily hours	7	6	6	6
Mean Power	22	16	8	8
Min Power	20	15	5	5
Max Power	40	40	9	9

Table 3-3: Usage of TV without second-hand one

Television		N	%	Annual Energy saved(kWh)
LG	New	37	15.7447	
	SH-> New	9	3.82979	316.3299173
SAMSUNG	New	32	13.617	
	SH -> New	7	2.97872	246.03438
Philip	New	16	6.80851	
	SH-> New	15	6.38298	527.216529
SONY	New	9	3.82979	
	SH-> New	10	4.25532	351.477686
PRESIDENT	New	3	1.2766	
GRUNDING	New	2	0.85106	
	SH-> New	5	2.12766	175.738843
BEKO	New	1	0.42553	
SHARP	New	29	12.3404	
	SH->New	6	2.55319	210.886612
OTHER	New	22	9.361702	
	SH->New	32	13.61702	1124.728595
				2952.413

Table 3-4: Usage of freezers without second-hand one

FREEZERS		N	%	Annual Energy saved(kWh)
LG	New	4	9.523809524	
	SH-> New	1	2.380952381	106.8233334
BEKO	New	5	11.9047619	
	SH-> New	2	4.761904762	213.6466668
NASCO	New	2	4.761904762	
SHARP	New	6	14.28571429	
	SH-> New	2	4.761904762	213.6466668
OTHER	New	11	26.19047619	
	SH-> New	9	21.42857143	961.4100006
Total				1495.53

Table 3-5: Usage of refrigerator without second-hand one

REFRIGERATOR		N	%	Annual Energy saved(kWh)
LG	New	9	20	
	SH-> New	3	6.6666667	320.4700002
BEKO	New	4	8.8888889	
	SH-> New	1	2.2222222	106.8233334
NASCO	New	3	6.6666667	
	SH->New	1	2.2222222	106.8233334
Other	New	14	31.111111	
	SH->New	10	22.222222	1068.233334
Total				1602.350001

3.9.3 Scenario 3: Sensitivity scenario: all households are using efficient appliances.

No more incandescent bulbs, second-hand TVs, second-hand refrigerators and second-hand freezers in Lomé’s households. Incandescent bulbs are replaced by led bulbs and second-hand TVs, refrigerators and freezers are replaced by new brand one. More this scenario takes in consideration the technology aspect: all appliances in the Lomé’s market should be more efficient and follow the characteristics below (Table 3.6 to 4.10). The extreme case scenario is the combination of scenario2 and assumption made on appliances technology.

Table 3-6: TV characteristics and their yearly electricity consumption

TV	N		Hour		Mean	Median	Min. P(w)	Max P(w)	Mean yearly cons.(Wh)	Mean yearly cons. kWh
	Valid	Missing								
Power of TV LG	46	196	5		157.83	195	40	250	13249500	
Power of TV SAMSUNG	39	203	6		120.49	110	40	220	10290810	
Power of TV PHILIPPS	31	211	7		110.58	110	45	250	8758540	
Power of TV SONY	19	224	4		97.56	110	40	190	2706191.11	
Power of TV PRESIDENT	3	239	6		95	110	40	135	624150	
Power of TV GRUDING	7	235	4		109.29	110	60	155	1116900	
Power of TV NASCO	1	241	0		110	110	110	110	0	
Power of TV BEKO	1	240	3		67.5	67.5	40	95	73912.5	
Power of TV SHARP	35	209	5		101.91	90	45	195	6509443.18	
Power of Other TV	54	188	6		108.52	110	35	250	12833400	
									56162846.8	56162.8468

Table 3-7:AC characteristics and their yearly electricity consumption

AC	N		Mean Hours	Mean	Median	Min P(w)	Max P(w)	Mean yearly cons.(Wh)	Mean yearly cons. (kWh)
	Valid	Missing							
Power of ROYAL AIR	4	238	2	1987.5	1875	1200	3000	5803500	
Power of SHARP	2	240	1	1522.5	1522.5	1145	1900	1111425	
Power of ICE CRIME	1	241	1	1850	1850	1850	1850	675250	
Power of CLIMY	1	241	1	2015	2015	2015	2015	735475	
Total								8325650	8325.65

Table 3-8: Brewers characteristics and their yearly electricity consumption

BREWERS	N		Hours	Mean	Median	Min P(w)	Max P(w)	Mean yearly cons.(Wh)	Mean yearly cons.(kWh)
	Valid	Missing							
Power of BINATONE	22	220	4	66.14	75	45	75	2124300	
Power of PRESIDENT	1	241	3	55	55	55	55	60225	
Power of NEON	6	236	3	69.17	65	45	100	454425	
Power of SHARP	3	239	4	75	75	50	100	328500	
Power of the Other brewers	10	232	6	64.5	57.5	45	100	1412550	
Total								4380000	4380

Table 3-9:Ventilators characteristics and their yearly electricity consumption

VENTILATORS	N		Hours	Mean	Median	Min P(w)	Max P(w)	Mean yearly cons.(Wh)	Mean yearly cons.(kWh)
	Valid	Missing							
Power of BINATONE	88	154	5	56.99	50	40	100	9152375	
Power of BRUDER	15	227	4	47.67	45	45	55	1043900	
Power of PRESIDENT	6	236	4	55.83	50	40	100	489100	
Power of NEON	9	233	4	77.78	90	45	100	1022000	
Power of Other	44	198	6	51.7	50	30	100	4982250	
Total								16689625	16689.625

Table 3-10: Refrigerators characteristic and their electricity consumption

REFRIGERATOR	N		Hour	Mean	Median	Min P(w)	Max P(w)	Mean yearly cons.(Wh)	Mean yearly cons.(kWh)
	Valid	Missing							
Power of LG	12	230	8	115.42	120	65	120	4044200	
Power of BEKO	5	237	6	76	65	65	120	832200	
Power of NASCO	4	238	9	92.5	92.5	65	120	1215450	
Power of Other	20	222	10	117.25	120	65	150	8559250	
Total								14651100	14651.1

Chapter 4

4 RESULTS AND DISCUSSIONS

This chapter is dedicated for the results of the research and discussions. We had presented and discussed the models' validation, the results of the survey, the experiments and Lomé's system dynamic model.

4.1 Validation of the models

The models were calibrated and validated with the data of electricity consumption of Lomé's households for the period 2000-2016. The coefficient of correlation is 0.992 for the LECSDPHAE model and 0.983 for the model LECSDGPG. Figures 4.4 and 4.5 show the correlation between historical data and simulated data.

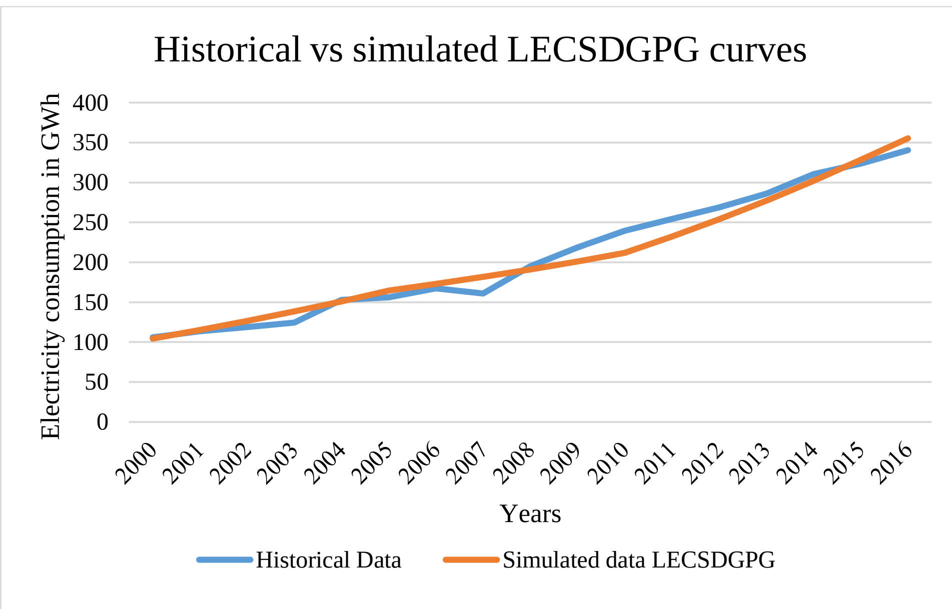


Figure 4-1:Validation of LECSDGPG model

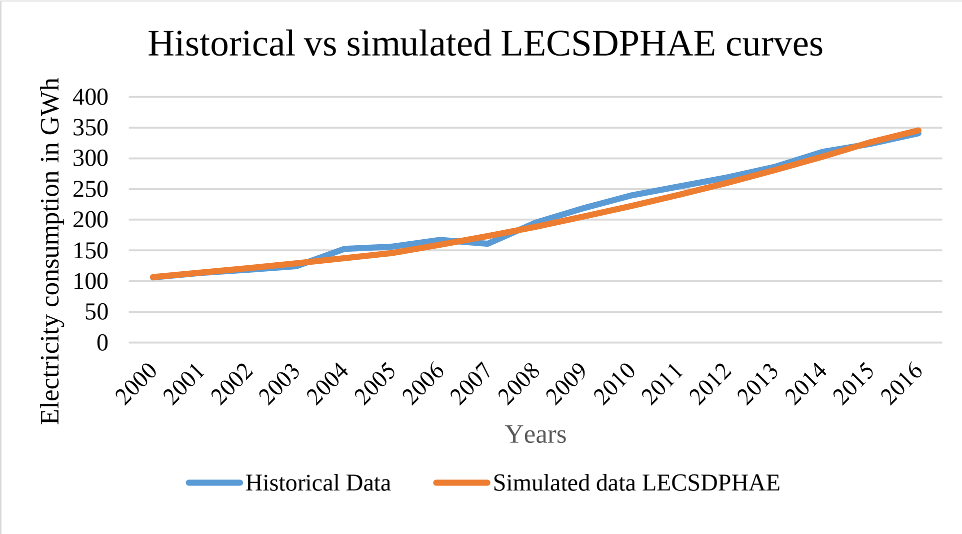


Figure 4-2:Validation of LECSDPHAE model

4.2 Lomé residential sector appliances assessment

The survey was analysed and the following results were obtained. The Capital of Togo like the other capitals of emerging countries is overflowed with different appliances in the residential sector. In the Lomé's households, there are different lamps and appliances like televisions, air conditioners, brewers, fans, freezers, refrigerators, and electric cookers.

4.2.1 Lamps assessment

In Lomé's households there are different types of lighting fixtures, such as Neon based, Fluorescent lamps, Led and Incandescent lamps. They represent approximatively a proportion of 34.9%, 49.7%, 11.8%, 2.4% and 1.1%, in that order. The details are illustrated in Table 4.1. The mean hours of usage per day is seven hours for Neon, six hours for Fluorescent, six hours for Led, and six hours for Incandescent as seen in Table 4.2 with the average lamps per households. For their power, the lamps have a mean power of 22W, 16W, 8W and 52W, respectively. The details are presented in table A.3, A.4 and A.5.

Table 4-1: Lamps frequencies

		Responses		Percent of Cases
		N	Percent	
Types of lamps	Neon	130	34.90%	53.70%
	Fluorescent	186	49.70%	76.40%
	Led	43	11.80%	18.20%
	Incandescent	8	2.40%	3.70%
	Other specify	4	1.10%	1.70%
Total		372	100.00%	153.70%

Table 4-2: Mean rated power and usage information of lamps

Lamps	Neon	Fluorescent	Led	Incandescent
Mean rated power(W)	22	16	8	52
Daily usage(hours)	7	6	6	6

4.2.2 Televisions assessment

97.1% of households in Lomé are using televisions. LG, SAMSUNG, PHILIP, SONY, PRESIDENT, GRUNDING, BEKO, SHARP and Other brands are the type of televisions used in Lomé’s residential sector with a proportion of: 19.6%, 16.6%, 13.2%, 8.1%, 1.3%, 3.0%, 0.4%, 14.9% and 23.0%, respectively as seen in Table 4.3. Details are presented in Table A.6. In Lomé’s household’s, used TVs are also being utilized and details on statistics are illustrated in figures 4.1. It is worthy to checking out the average age of TVs as shown the results in Tables 4.4 and A.7. Their average age varies from one year for BEKO brand to 6 years for SHARP brand. The latter table presents also their mean rated power and daily usage time. Television with the lowest mean rated power is the BEKO TV while LG TV has the highest mean rated power. In term of daily usage, the most utilized TV are PHILIP (7 hours) but PRESIDENT, SAMSUNG and the one grouped in ‘Other’ (6 hours) followed by LG, SHARP, and SONY (5 hours).

Table 4-3: Television's statistics

		Responses		Percent of Cases
		N	Percent	
Marks of TV	LG	46	19.60%	21.80%
	SAMSUNG	39	16.60%	18.50%
	PHILIPPS	31	13.20%	14.70%
	SONY	19	8.10%	9.00%
	PRESIDENT	3	1.30%	1.40%
	GRUDING	7	3.00%	3.30%
	BEKO	1	0.40%	0.50%
	SHARP	35	14.90%	16.60%
	Other	54	23.00%	25.60%
Total		235	100.00%	111.40%

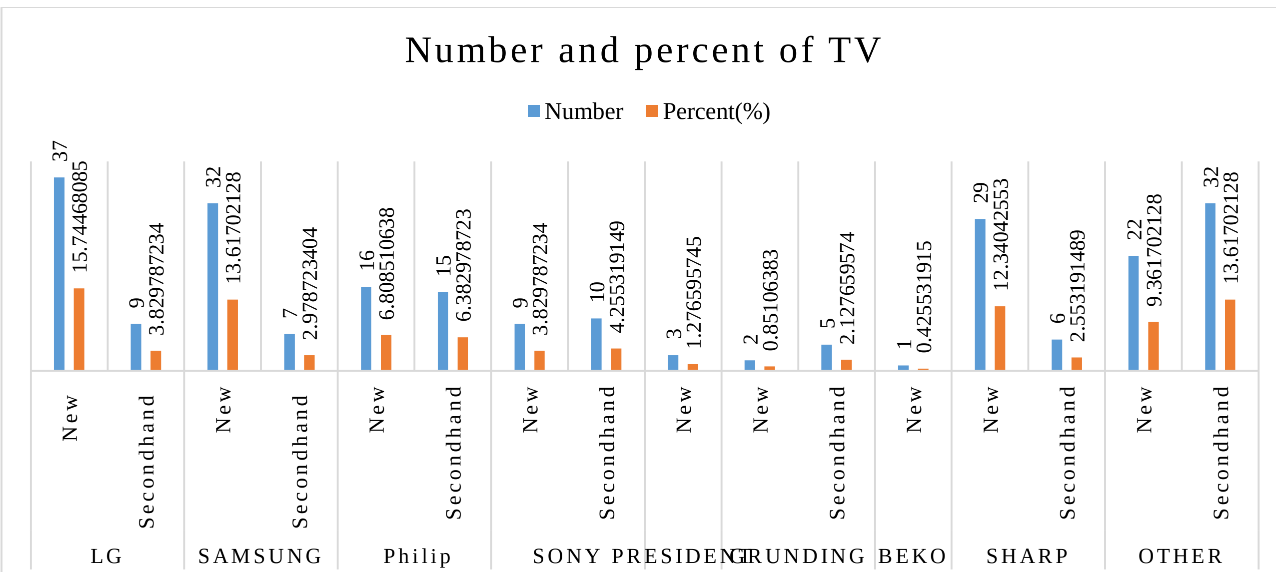


Figure 4-3:Number of type of TV

Table 4-4: Television mean rated power and usage information

Television mean rated power and usage information										
	LG	SUMSUNG	PHILIPPS	SONY	PRESIDENT	GRUDING	NASCO	BEKO	SHARP	Other
Average years of usage	4.76	4.38	5.9	5.4	3.67	4		1	5.48	4.53
Mean rated power(w)	193.63	120.49	127.1	97.56	95	109.29	110	67.5	101.91	118
Daily usage(hours)	4.93	5.72	6.76	4.33	6.33	4		3	4.74	5.94

4.2.3 Air conditioners assessment

According to the sample results considered in the study, only 3.3% households are using an air conditioner. The most common types encountered are ROYAL AIR, SHARP, ICE CRIME and CLIMY as seen in figure 4.2. From the latter graph, only ICE CLIMY is a second-hand appliance with a negligible percent. Table 4.5 presents the number of years they are in service. Their mean power is respectively: 2196.25W, 1522.50W, 1850.00W and 2015.00W and they were "ON" three hours per day, and the remain one, is one hour per day as seen in the latter table. Details are presented in the table A.8.

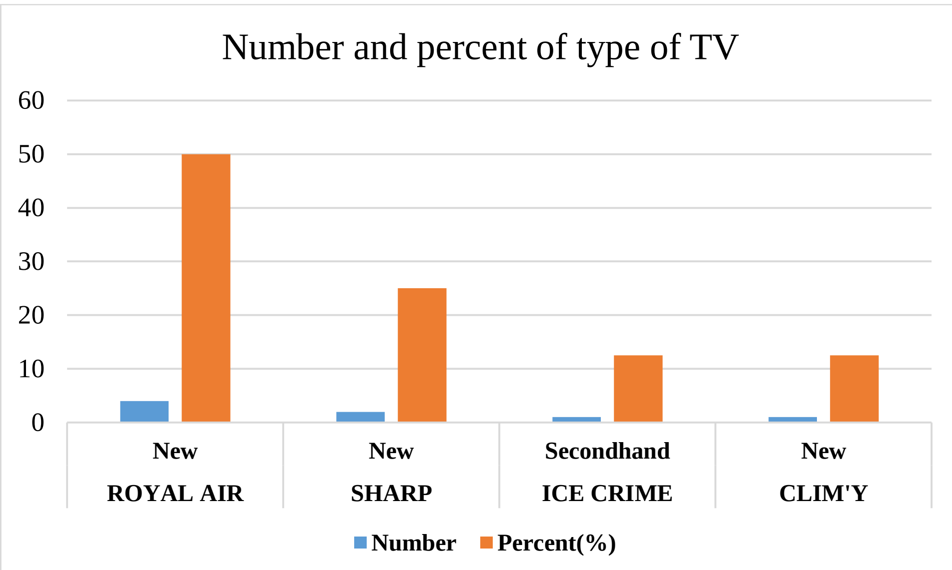


Figure 4-4:: Number and percent of type of TV

Table 4-5: AC mean rated power and usage information

AC mean rated power and usage information	ROYAL AIR	SHARP	ICE CRIME	CLIMY
Average years of usage	3.5	4.5	20	3
Mean power(w)	2196.25	1522.5	1850	2015
Daily usage(hours)	2	1	1	1

4.2.4 Brewers assessment

The survey revealed that in Lomé residential sector, different type of brewers is being used (Table 4.6). The most frequent brewers found are BINATONE, SHARP, and NEON. Also, only BINATONE, PRESIDENT, and NEON are new brands. Figure 4.3 shows the number and the percent of each item. Their years of usage vary from 3 to 7 years as can be seen in table 4.7 with their mean rated power. NEON and SHARP have the highest mean rated power. The brands grouped in 'Other', BINATONE and Sharp are mostly "ON".

Table 4-6: Brewers' statistics

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	BINATONE	22	9.1	51.2	51.2
	PRESIDENT	1	0.4	2.3	53.5
	NEON	6	2.5	14	67.4
	SHARP	3	1.2	7	74.4
	EVERNAL	1	0.4	2.3	76.7
	ORL/CMC	1	0.4	2.3	79.1
	MC	1	0.4	2.3	81.4
	ELBEE	1	0.4	2.3	83.7
	RAKS	1	0.4	2.3	86
	MIX AIR	1	0.4	2.3	88.4
	SMC	1	0.4	2.3	90.7
	Unknown	2	0.8	4.7	95.3
	MSET	1	0.4	2.3	97.7
	SMT	1	0.4	2.3	100
	Total	43	17.8	100	
Missing	System	199	82.2		
Total		242	100		

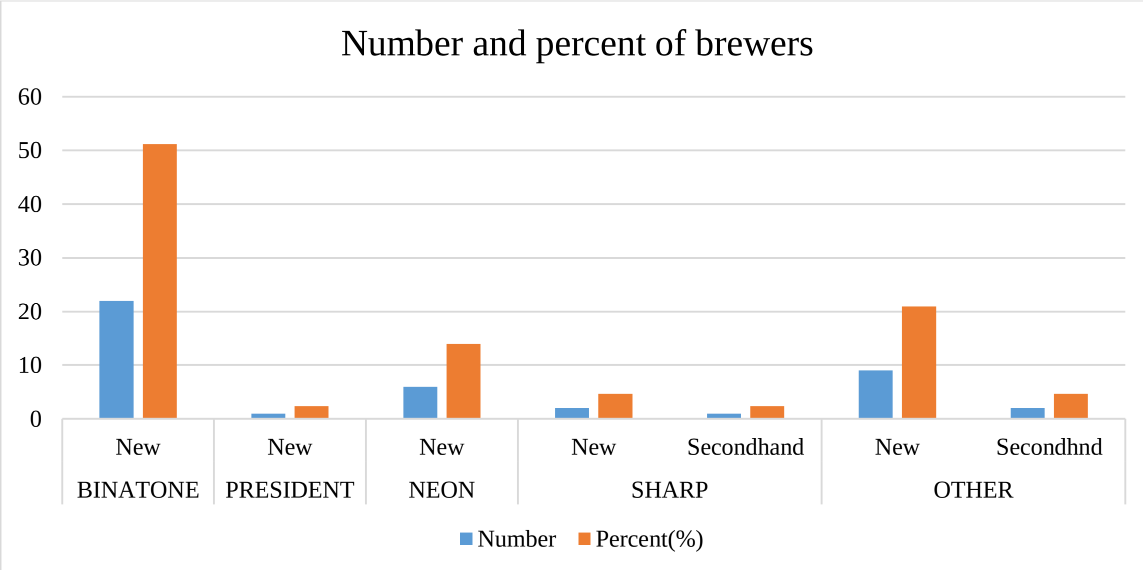


Figure 4-5:Number and percent of Brewers

Table 4-7: Mean rated power and usage information of brewers

Brewers	BINATONE	PRESIDENT	NEON	SHARP	Other
Average years of usage	5.55	7	3.67	7	3
Mean rated power(w)	66.14	55	78.33	78.33	68.1
Daily usage(hours)	4	3	3	4	6

4.2.5 Ventilators assessment

66.94% inhabitants out of the sample possesses ventilators. Their types and frequency of usage are presented in Table 4.8. In Lomé's residential sector, BINATONE, BRUDER, PRESIDENT, NEON, and NULEK are most used appliances with BINATONE taking the lead. Figure 4.4 presents the quality of appliances, irrespective of their state as newly brought or second-hand. Table 4.9 presents the mean rated power, the average age and average daily in hours for each items. They have been in service for: 1) two years for NEON and 2) five years for BRUDER and PRESIDENT as seen in the latter table. It can be noticed that NEON has the highest mean rated power and BRUDER has the lowest one. In terms of their daily usage, most used are the "Others" with more than five hours per day. BINATONE is "ON" five hours per day and the remain one four hours per day.

Table 4-8: Ventilators' Frequencies

		Responses		Percent of Cases
		N	Percent	
Ventilators brands	BINATONE	85	52.47%	58.90%
	BRUDER	18	11.11%	11.90%
	PRESIDENT	6	3.60%	4.00%
	NEON	8	5.30%	6.00%
	NULEK	6	4.10%	4.60%
	MITSUI	5	3.00%	3.30%
	PUR GRQND	4	2.40%	2.60%
	ROCH	6	3.60%	4.00%
	SOREX	1	0.60%	0.70%
	HITACHIE	1	0.60%	0.70%
	LONGSON	2	1.20%	1.30%
	FGC	1	0.60%	0.70%
	NQSCO	1	0.60%	0.70%
	GOLF	1	0.60%	0.70%
	SUPER CROWN	2	1.20%	1.30%
	SHARP	2	1.20%	1.30%
	AFRICOOL	1	0.60%	0.70%
	WEST POINT	1	0.60%	0.70%
	INCONNUE	6	3.60%	4.00%
	ELBEE	1	0.60%	0.70%
	NEW CREN	2	1.20%	1.30%
	TIR-RI	1	0.60%	0.70%
	SIEMENS	1	0.60%	0.70%
	ROVEX	1	0.60%	0.70%
Total		162	100.00%	111.90%

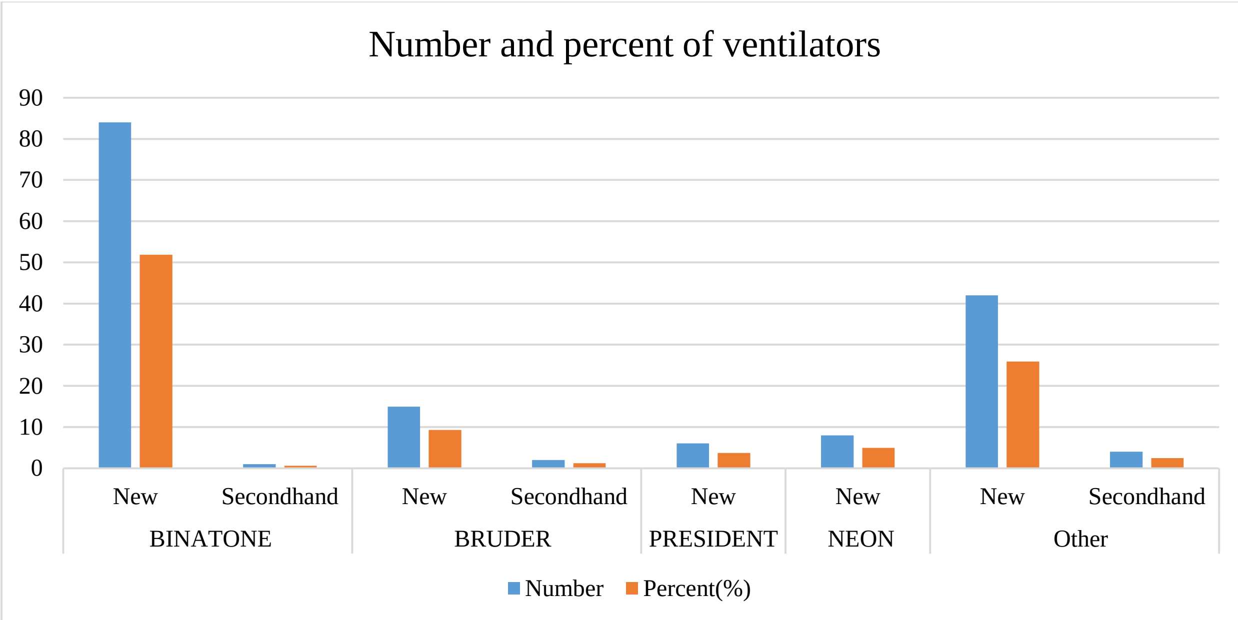


Figure 4-6:Number and percent of Ventilators

Table 4-9: Number and percent of Ventilators

Ventilators mean rated power and usage information					
	BINATONE	BRUDER	PRESIDENT	NEON	Other
Average years of usage	4.02	4.8	5.33	2.22	3.74
Mean rated power(w)	63.86	47.67	65	85.56	53.53
Daily usage(hours)	4.99	3.59	3.75	3.6	5.49

4.2.6 Freezers assessment

16.9% of households in Lomé are using freezers. Many different freezers are used such as for example LG, BEKO, NASCO, SHARP (Table 4.10). SHARP freezers is the most used (18.6%) followed by BEKO freezer (16.3%). Figure 4.5 presents the number and the proportion of freezers, irrespective of their state as newly brought or second-hand. Clearly, in Lomé, it can be seen in houses used and new brand freezers. The age of freezers starts from three years for BEKO and Other to seven years for SHARP as presented in the table 4.11. Freezers' mean rated power is as follows: 184.50W for LG, 201.67W for BEKO, 184.00W for NASCO, 498.38W for SHARP and 211.73W for the other. One can notice that SHARP freezer has the highest rated power and freezer

NASCO has the lowest rated power. For daily usage, other freezers are more used followed by LG and BEKO. The mean rated power and the daily usage are presented in the latter table.

Table 4-10: Freezers frequencies

		Responses		Percent of Cases
		N	Percent	
Freezer brands	LG	5	11.60%	12.20%
	BEKO	7	16.30%	17.10%
	NASCO	2	4.70%	4.90%
	SHARP	8	18.60%	19.50%
	Other	6	14.00%	14.60%
	BOSH	2	4.70%	4.90%
	BACO	1	2.30%	2.40%
	OCEAN	3	7.00%	7.30%
	PHILIPPS	2	4.70%	4.90%
	CARISTON	1	2.30%	2.40%
	SOLD STAR	2	4.70%	4.90%
	WANBAO	1	2.30%	2.40%
	LIEBHERR	2	4.70%	4.90%
	NEON	1	2.30%	2.40%
Total		43	100.00%	104.90%

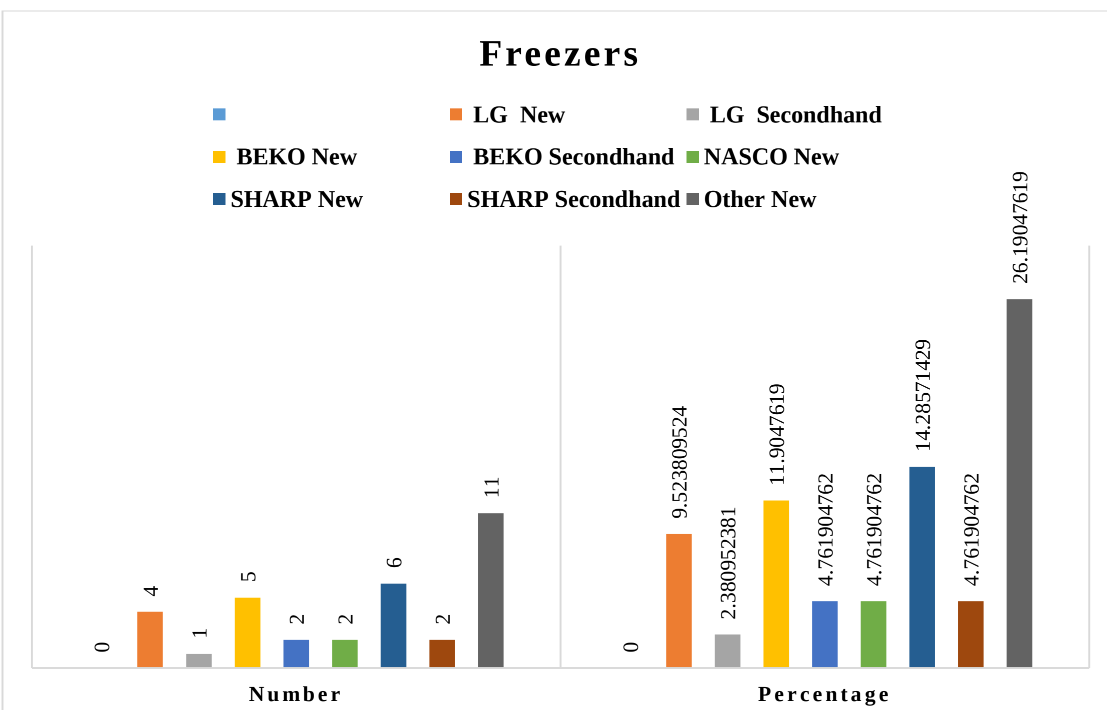


Figure 4-7:Number and percent of Freezers

Table 4-11: Number and percent of Freezers

Freezers mean rated power and usage information	LG	BEKO	NASCO	SHARP	Others
Average years of usage	4.8	3	4	6.86	3.05
Mean rated power(w)	184.5	201.67	184	498.38	211.73
Daily usage(hours)	7	7.5	4	3.75	12

4.2.7 Refrigerators assessment

The refrigerators quota amongst the residential household's appliances in the capital was found to be 18.6%. Their types and frequency of usage are presented in the Table 4.12. The LG brand was the most common item found, followed by the BEKO, NASCO and SHARP as presented in the same Table. As for the freezers, the refrigerators can be new brand or second-hand. It exists second-hand and new brand for LG, BEKO, NASCO, and Other as seen in the figure 4.6 with their proportion. The average years of usage of the refrigerators varies from two years for BEKO to four years for NASCO and LG. The LG refrigerator is mostly used in daytimes than the other marks. As it can be seen in the Table 4.13, the BEKO mark has the lowest mean rated power (112.00W) and all other marks grouped under "Other" have the highest rated power (134.00W). Concerning the daily time usage, the average number of hours is 10 hours for the mark 'Other', nine hours for NASCO, eight hours for the mark LG and six hours for the mark BEKO as seen in the latter table.

Table 4-12: Frequencies on Refrigerators

		Responses		Percent of Cases
		N	Percent	
Refrigerators Brands	LG	12	26.10%	26.70%
	BEKO	5	10.90%	11.10%
	NASCO	4	8.70%	8.90%
	SHARP	4	8.70%	8.90%
	LIBER	1	2.20%	2.20%
	IDEAL	1	2.20%	2.20%
	WESTPOINT	1	2.20%	2.20%
	SAMSUNG	2	4.30%	4.40%
	INCONNUE	3	6.50%	6.70%

WHIRL POOL	1	2.20%	2.20%
PHILIPPS	1	2.20%	2.20%
NEON	1	2.20%	2.20%
ICON	1	2.20%	2.20%
LIEBHERR	2	4.30%	4.40%
INDESIT	1	2.20%	2.20%
SIEMENS	1	2.20%	2.20%
YOKOMATO	1	2.20%	2.20%
SUZIKA	1	2.20%	2.20%
WESTPOWER	1	2.20%	2.20%
A+	1	2.20%	2.20%
IGNIS	1	2.20%	2.20%

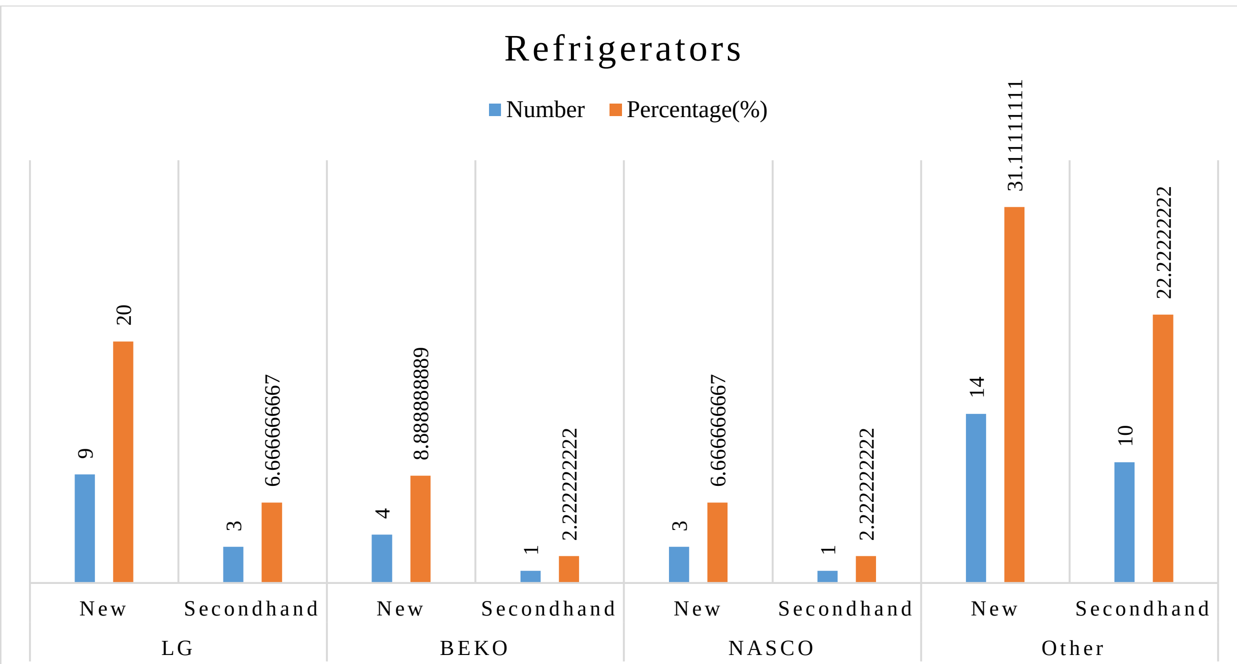


Figure 4-8:Number and percent of Refrigerators

Table 4-13: Refrigerators mean rated power and usage information

Refrigerators mean rated power and usage information	LG	BEKO	NASCO	Other
Average years of usage	4.33	2	4.25	3.22
Mean rated power(w)	171.67	112	122.5	134
Daily usage(hours)	8.17	5.8	9.25	10.32

4.2.8 Electric Cooker assessment

The electric cooker is the least appliance used in Lomé's residential sector with 1.7% as seen in table 4.14. Interestingly, all the electric cookers are brand new. Their years of usage are from two for FIDES and STUDIO, six for LG, and seven for MIELE. The average usage of the appliances is one hour per day. Also, only the rated power of MIELE is known (350W).

Table 4-14: Electric Cookers Frequencies

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	LG	1	0.4	25	25
	FIDES	1	0.4	25	50
	MIELE	1	0.4	25	75
	STUDIO	1	0.4	25	100
	Total	4	1.7	100	
Missing	System	238	98.3		
Total		242	100		

4.3 Drivers appliances of electricity consumption in Lomé's residential sector

From the above assessment, the annual electricity consumption per each type of appliance and the percentage are estimated and presented in the table 4.15. Figure 4.7 highlights the abovementioned information. It appears that the appliances that driver the residential electricity consumption in Lomé are Televisions, Freezers, Brewers, Fans, and Lamps, irrespective of the brands. Televisions are the most significant drivers followed by Freezers.

Table 4-15: Estimation of annual electricity consumption and percentage of appliances assessed

Appliances	*Lamps	**TV	AC	Brewers	*Ventilators	*Freezers	*Refrigerators	Electric Cooker
Annual electricity consumption (kWh)	15489.140	60836.04	8812.8	4324.543	17215.911	31385.029	20135.707	255.5
%	10	38.4	5.6	2.7	11	20	13	0.16

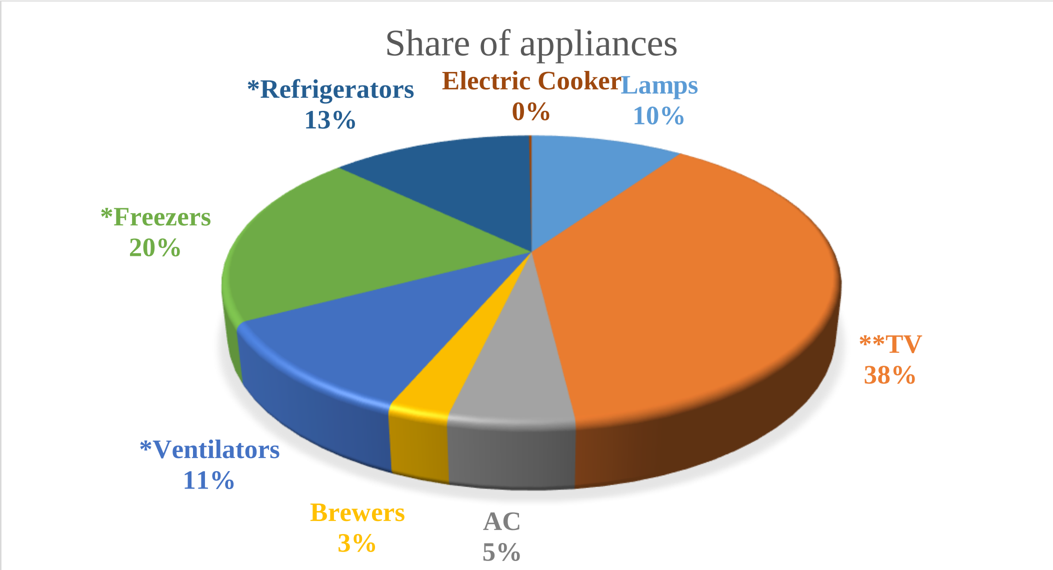


Figure 4-9:Percentage of electricity consumption per appliances

4.4 Socio-economic households in Lomé

As a result of the survey, it can be pointed out that, in Lomé, there are five categories of socio-economic households: 1) houses with light fixtures only, 2) houses with light fixtures and television, 3) houses with light, television and ventilator,4) houses with light, television, ventilator and/or brewer, and refrigerator and/or freezer, and 5) houses with light, television, ventilator and/or brewer, refrigerator and /or freezer, air conditioner and electric cooker.

4.5 Knowledge gained from the experiments

During and after the completion of the experiments, the results revealed that the electricity consumption of the appliances mainly depends on its condition, i.e., brand new, relatively new or used. The latter consumes more electricity than the new brands ones. The difference in electricity consumption between brand-new and used appliances is primarily due to the aging factor rather than any difference in nominal power. Since the experiments were conducted on refrigerator-freezers, the difference in electricity consumption related to refrigerator-freezers is typically applicable to either refrigerators or freezers. The results of the experiments are presented in the figures 4.8 and 4.9. The second-hand TV's consumption was 47.43Wh which represents a 0.87Wh for the used TV. For the new brand appliance, the average electricity consumption is 28.2Wh corresponding for a consumption between 0.16Wh and 0.63 Wh. On the other hand, the used refrigerator-freezer's electricity consumption was 2717.33Wh per day (113.2Wh per hour); the new brand one's is 2424.67Wh per day (101.03Wh per hour) which corresponds for a consumption between 15.95Wh and 18.94 Wh. The difference in electricity consumption between the two TV was found to be 34,666Wh per year. For the refrigerator-freezers, the difference was 106,823Wh per year.

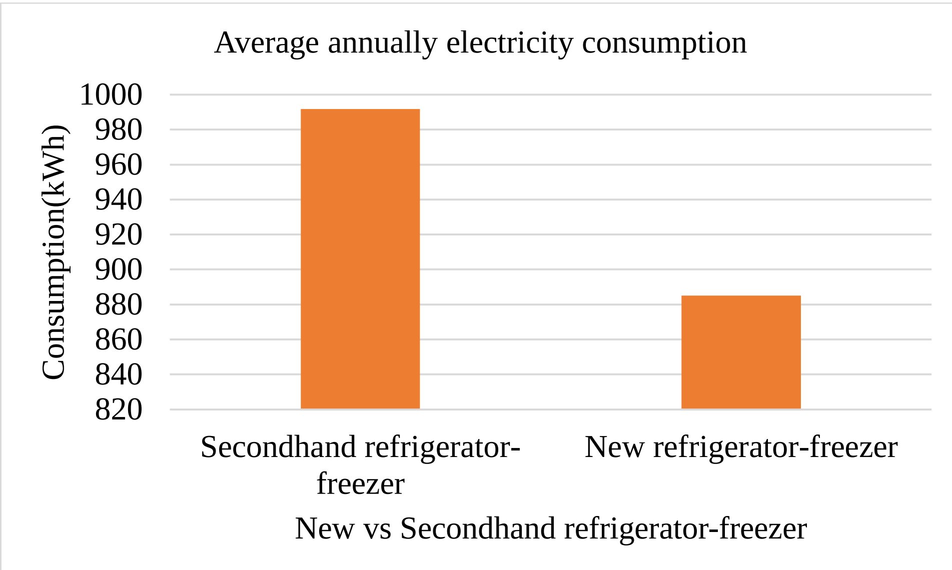


Figure 4-10:Comparison of electricity consumption of used vs new brand refrigerator-freezer

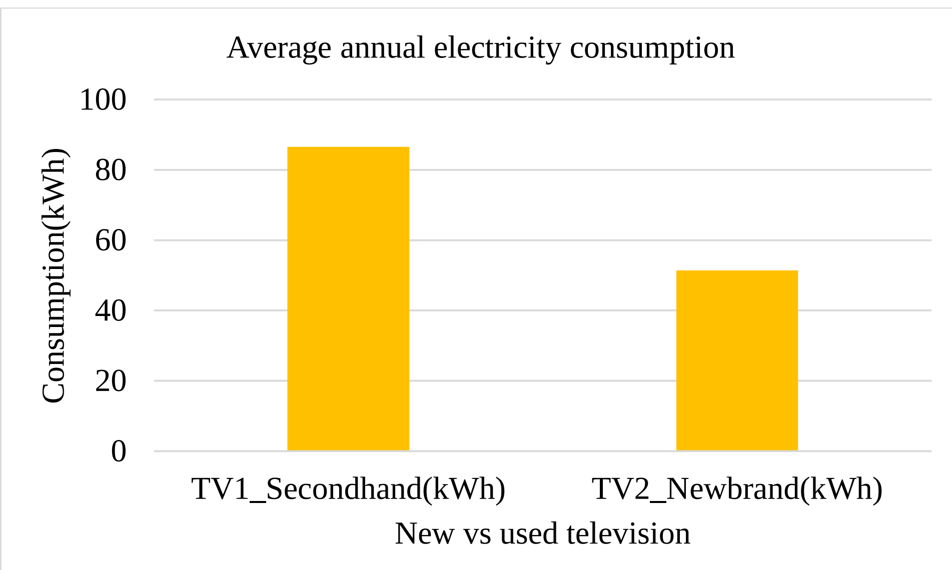


Figure 4-11:: comparison of electricity consumption of used vs new brand TV

4.6 Assessment of Lomé's residential electricity demand and future trends: near future 2030 and far future 2050

Electricity demand of the housing sector in Lomé is a function of the number of people, the GDP growth, and per capita electricity consumption (Figure 4.10). Also, the electricity demand is a function of the number of current households with access to electricity and the newly built houses having access to electricity (Figure 4.11). Figure 4.10 highlights the first patterns of electricity demand in Lomé's residential area.

LECSDGPG model's graph shows that electricity consumption in households of Lomé increases with population as well as GDP growth during the past sixteen years (2000 to 2016) and even beyond. It is expected to obey this law in the near future 2030 and the far future 2050. Both GDP and population growth help to understand the nature and the real drivers of the electricity consumption in Lomé's housing sector.

It is therefore a fact that an increase in population and economic growth are mainly responsible for an increase in electricity consumption. Consequently, the country must look into new and alternative ways to generate more electricity.

Figure 4.11 highlights the second patterns of electricity consumption in Lomé. With the LECSDPHAE's model, it can be seen that a growth of households having access to electricity burdens the electricity consumption in Lomé's residential sector. The impact of the number of houses with electricity is perceived in the past and in the future.

In 2030 and 2050 the population of Lomé will be respectively 3,145,787 and 5,529,168 habitants, respectively in the LECSDGPG model.

The corresponding electricity consumption will be 827GWh and 2,722GWh, also in that order. As for the LECSDPHAE model, in 2030 and 2050 the electricity consumption will be 828GWh and 2,513GWh with respective 457,240 and 1,105,834 households having access to electricity.

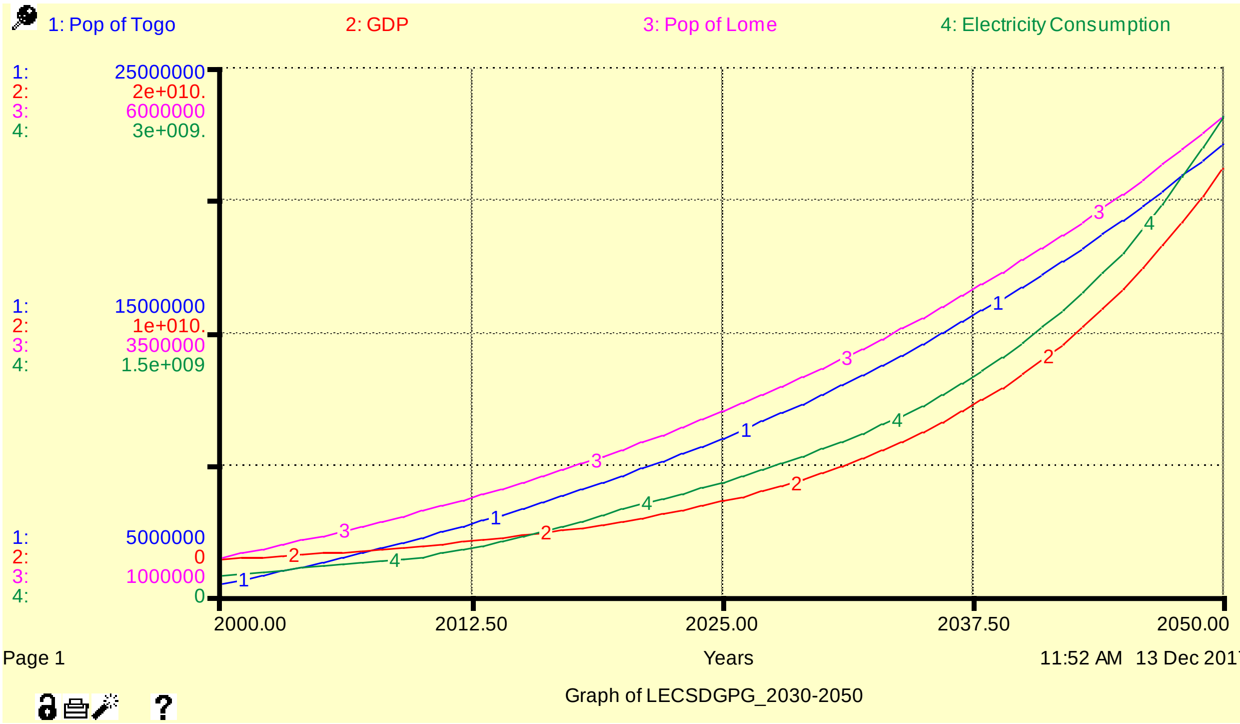


Figure 4-12:Electricity consumption increases with population and GDP growth

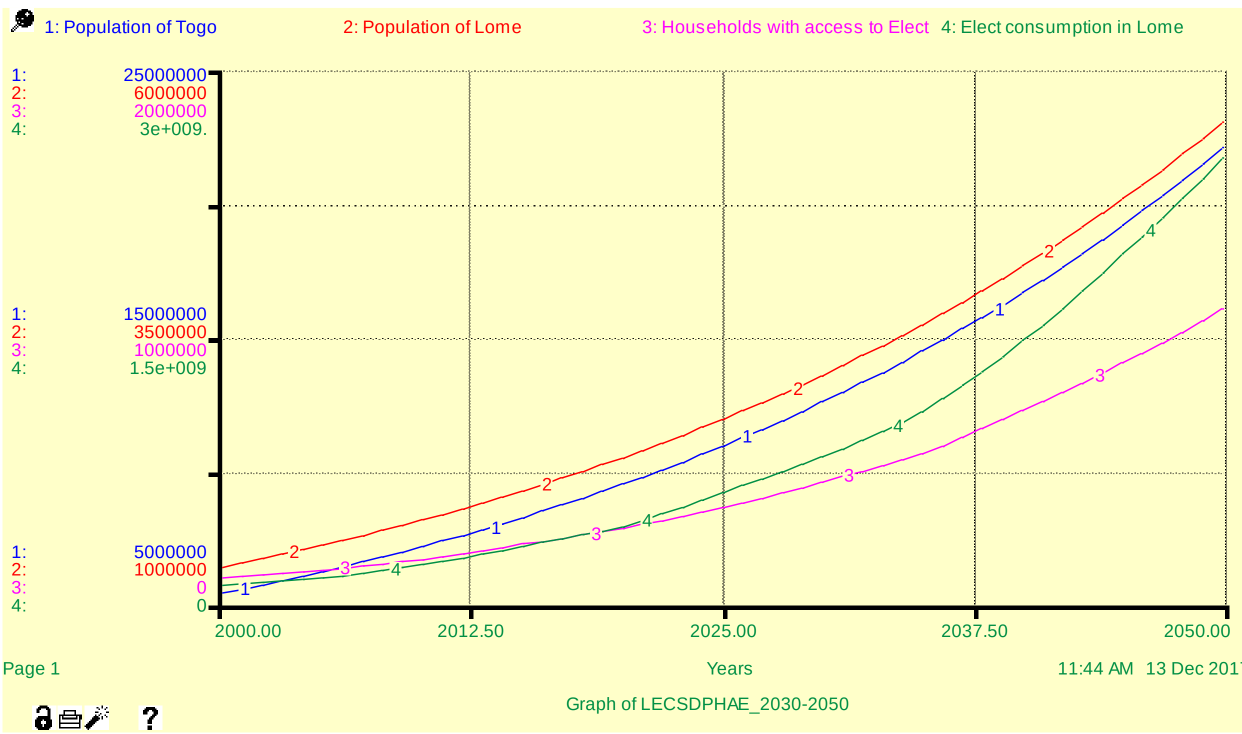


Figure 4-13:Electricity consumption increases with Households with access to electricity

4.7 Energy Efficiency Scenarios

4.7.1 Scenario1: Business-As-Usual(BAU)

Under the BAU, the general trends are as described in (Figure 4.10 and 4.11) because of introduction of any new energy efficiency policies.

4.7.2 Scenario2: Some households are using efficient appliances

The usage of efficient lamps and elimination of second-hand appliances is the major to reducing electricity consumption in the city. Regarding the lamps of the sample, the yearly electricity consumption is estimated at 15489.140kWh. The figure 4.14 presents the share of electricity consumption per lamps.

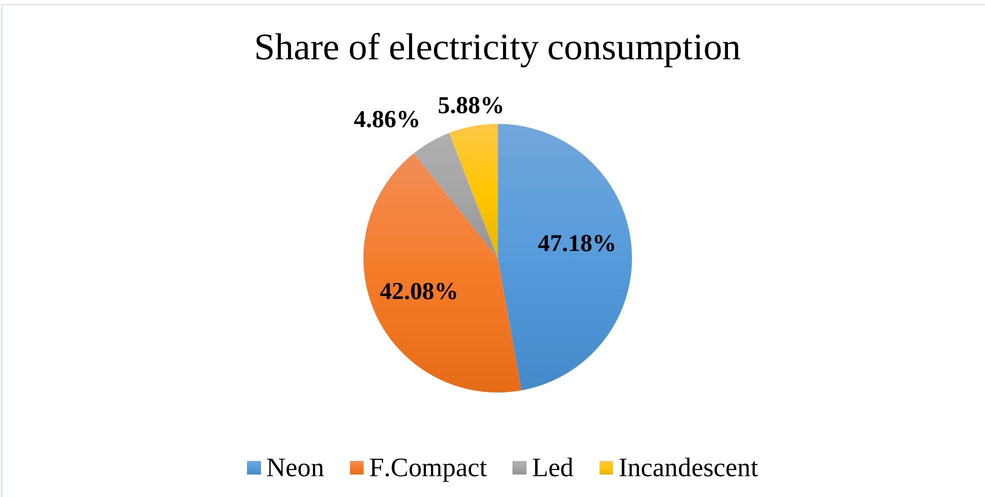


Figure 4-14:Electricity consumption per lamps

With the consideration of the assumption made under this scenario, the yearly electricity consumption becomes 14718.260 kWh. A rapid comparison gives a reduction of 771 kWh.

Basing on the experiment conducted on TV, refrigerators and freezers; the replacement of second-hand appliances with new or relatively new one allows to save electricity up to 3024 kWh for TV, 1605 kWh for Refrigerators and 1498 kWh for the freezers. Without any assumption, the total yearly electricity consumption of all appliances of the sample is estimated at 158454.67 kWh that gives a share of electricity per appliances represented in figure 4.15.

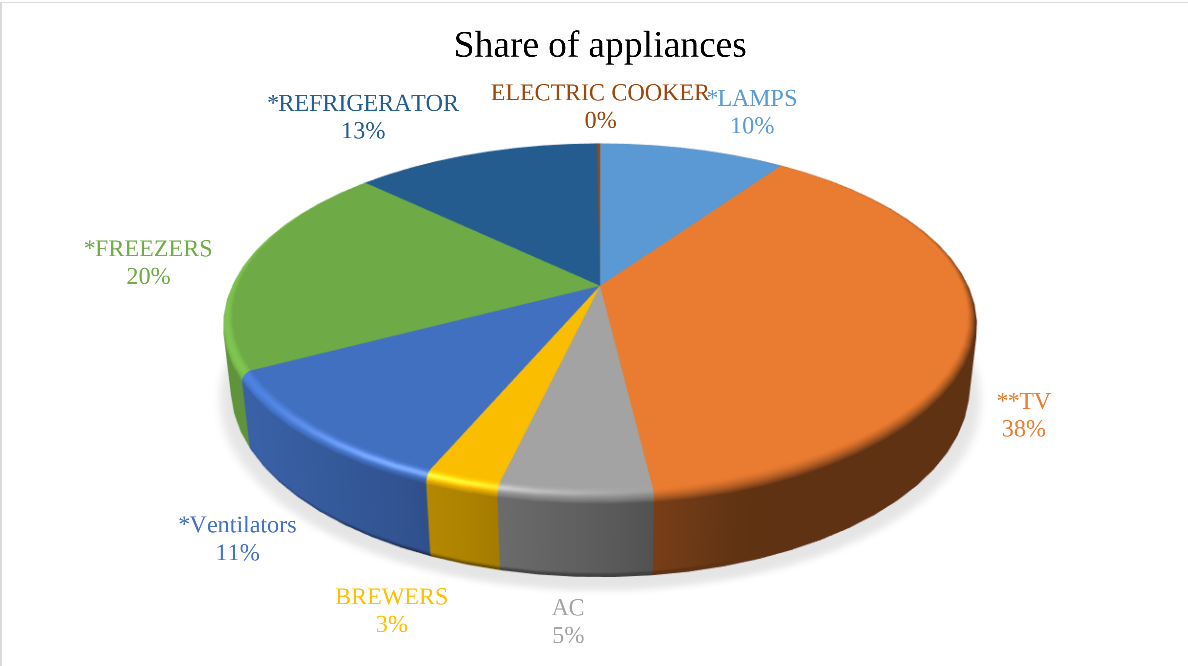


Figure 4-15:Electricity consumption per appliances

Combining the electricity saved from lamps, TV, refrigerators and freezers; the total electricity saved is 6898 kWh representing electricity reduction of 4.4%. This result concerns the sample. Therefore, the electricity consumption in Lomé's residential sector varies from 371GWh in 2018 to 792GWh in 2030; then is increased to at least 2,403GWh in 2050 with LECSDPHAE model as seen in figure 4.13. In contrast, with LECSDGPG model, the electricity consumption varies from 397GWh in 2018 to at least 790GWh in 2030; it then increases to 2,603GWh at least in 2050 as can be seen figure 4.12.

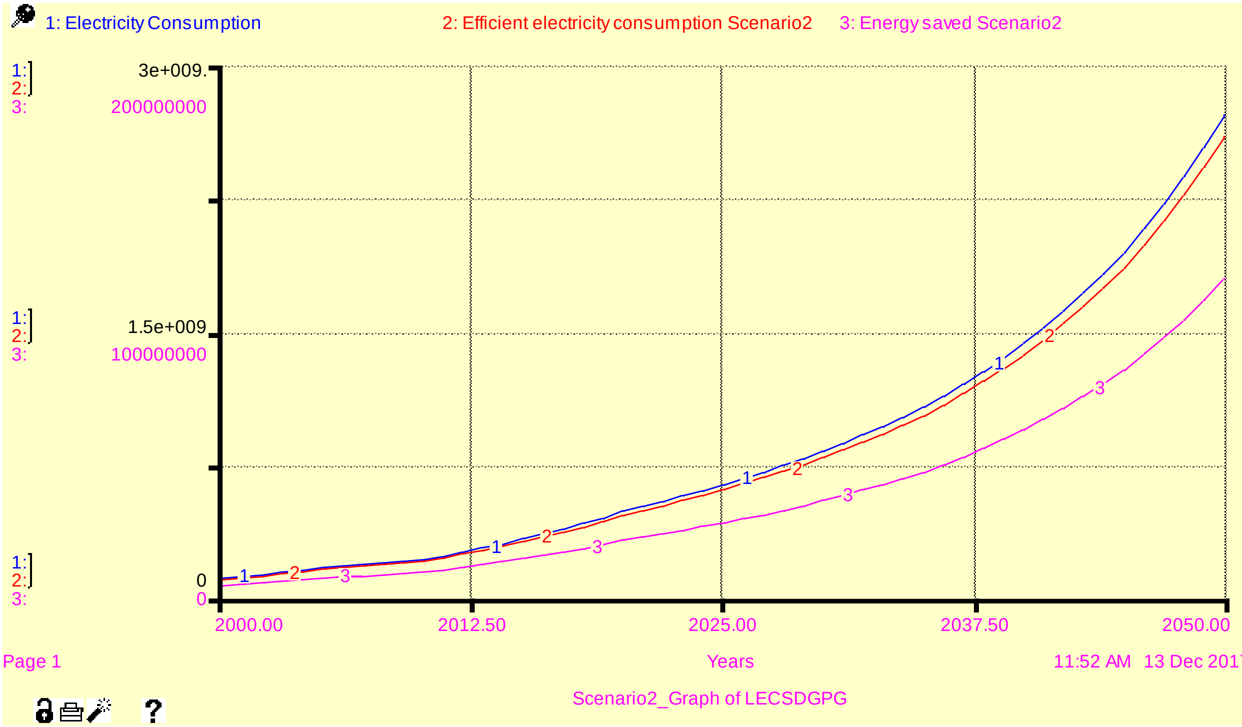


Figure 4-16:: Trends of electricity consumption, efficient electricity consumption and electricity saved (LECSDGPG)-Scenario2

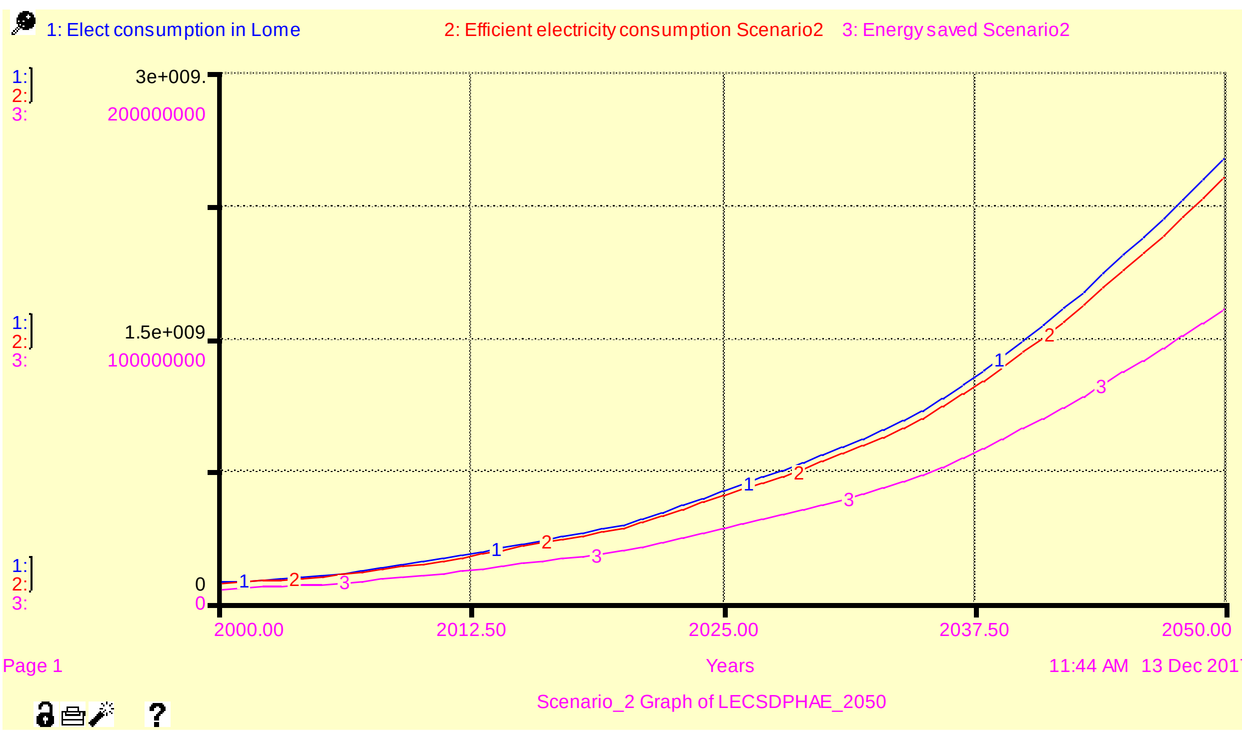


Figure 4-17:Trends of electricity consumption, efficient electricity consumption and electricity saved (LECSPHAE)-Scenario2

Figure 4-17: Trends of electricity consumption, efficient electricity consumption and electricity saved (LECSPHAE)-Scenario2

The two models put together present a good correlation concerning their results as illustrated in the figures 4.14.

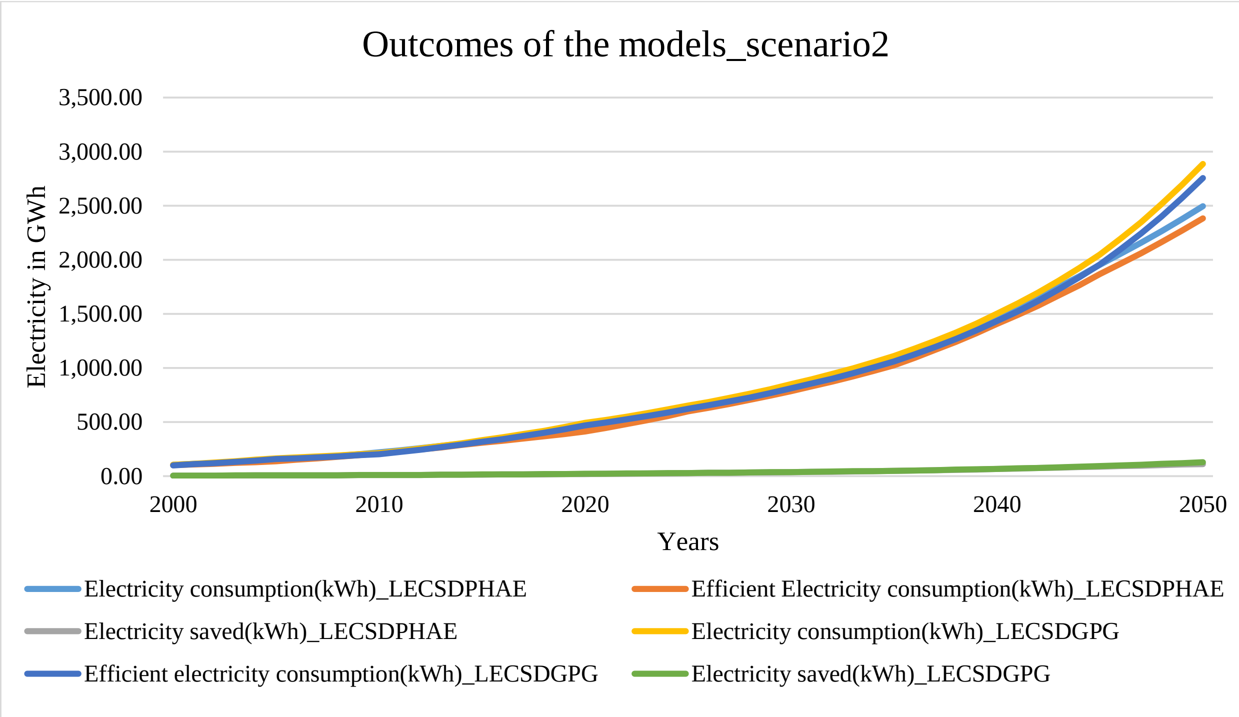


Figure 4-18:Outcome of the models_Scenario2

4.7.3 Scenario3: Sensitivity scenario

Under this extreme scenario, the reduction in the electricity consumption was more important than in scenario2. The electricity saved is so the sum of electricity saved in scenario2 and the electricity saved when using more efficient appliances. The electricity saved can be expressed as the sum of 6898 kWh and 37773 kWh which is the electricity saved basing of assumption made on appliances technology. The total electricity saved is 44593.9 kWh representing 28.2% of electricity reduction. Figures 4.15 and 4.16 precisely show the electricity consumption, efficient electricity consumption, electricity saved and their trends up to the year 2050. The electricity consumption in Lomé's residential sector varies from 279GWh in 2018 to 595GWh in 2030; it then increases to 1,805GWh in 2050. The results given by the LECSDPHAE model are portrayed in the figure 4.15. In addition, for the LECSDGPG model, the consumption varies from 298GWh in 2018 to 594GWh in 2030; it then increases to 1,955GWh in 2050. Figure 4.16 presents the trends of the results.

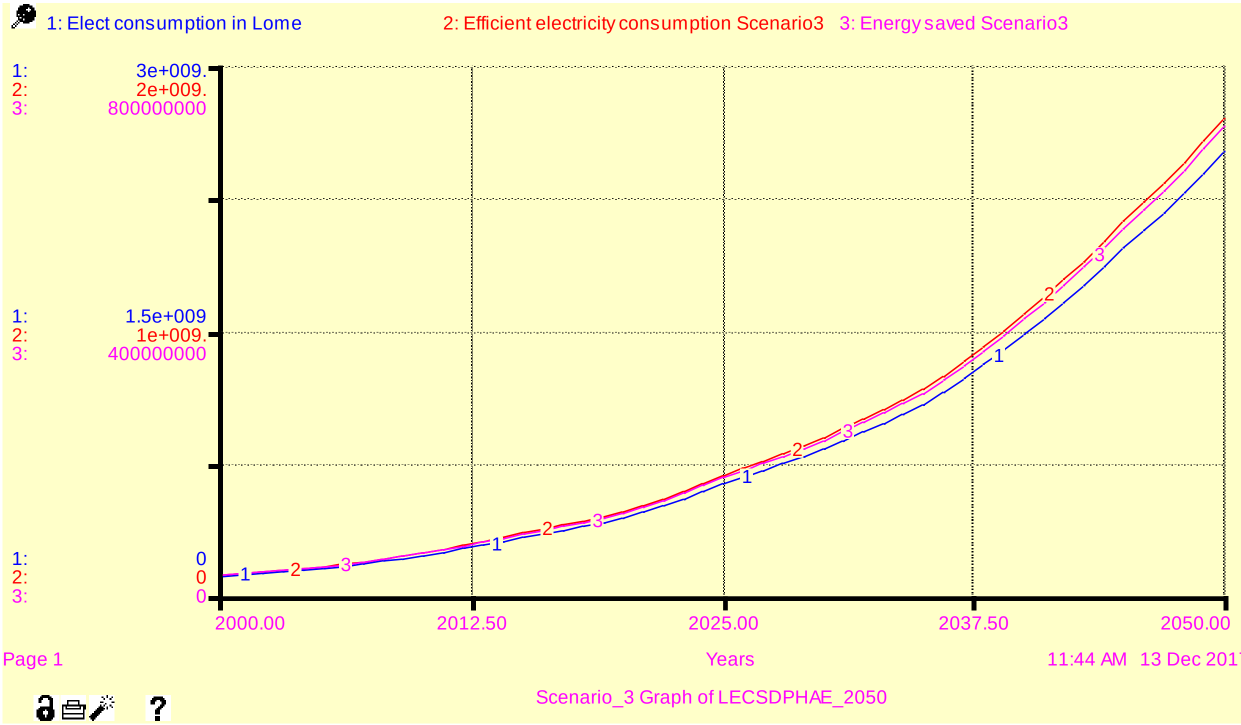


Figure 4-19:Trends of electricity consumption, efficient electricity consumption and electricity saved (LECSDPHAE)-Scenario3

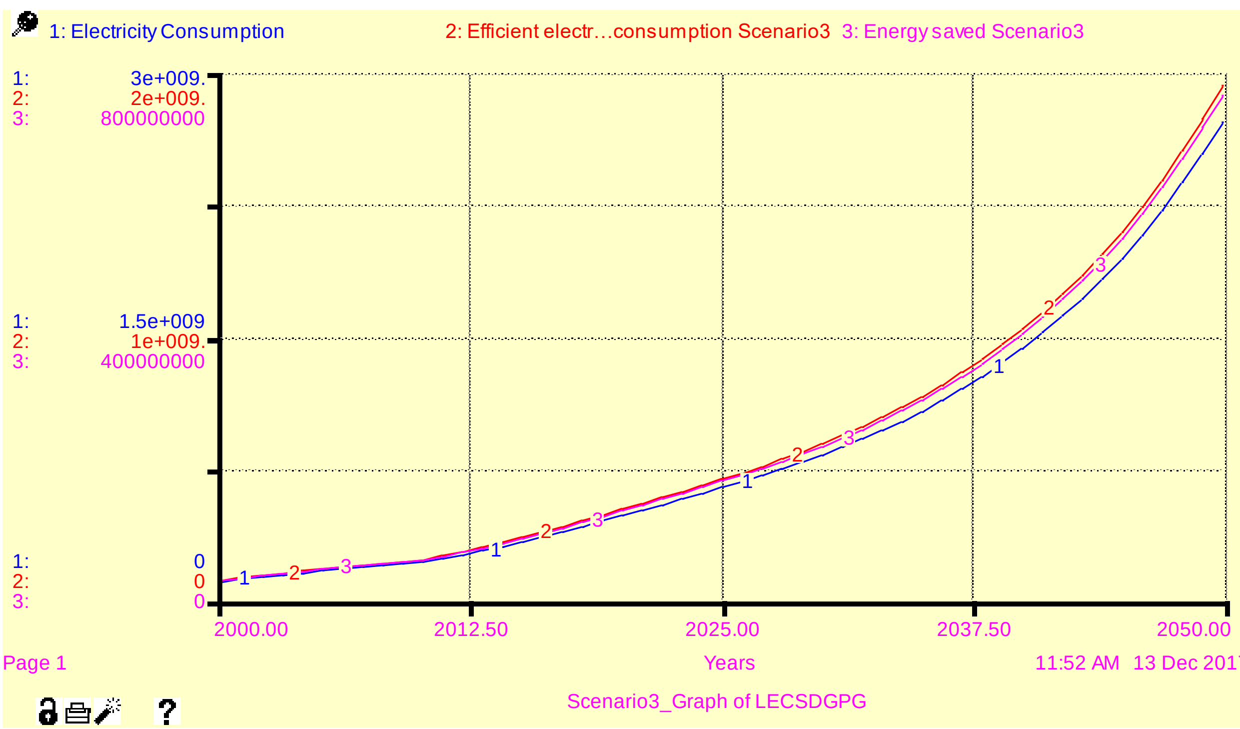


Figure 4-20:Trends of electricity consumption, efficient electricity consumption and electricity saved (LECSDGPG)_Scenario3

Figure 4-20: Trends of electricity consumption, efficient electricity consumption and electricity saved (LECSDGPG)_Scenario3

The trends of electricity consumption, efficient electricity consumption, and electricity savings in the two models are put together and underlined in the figure 4.17.

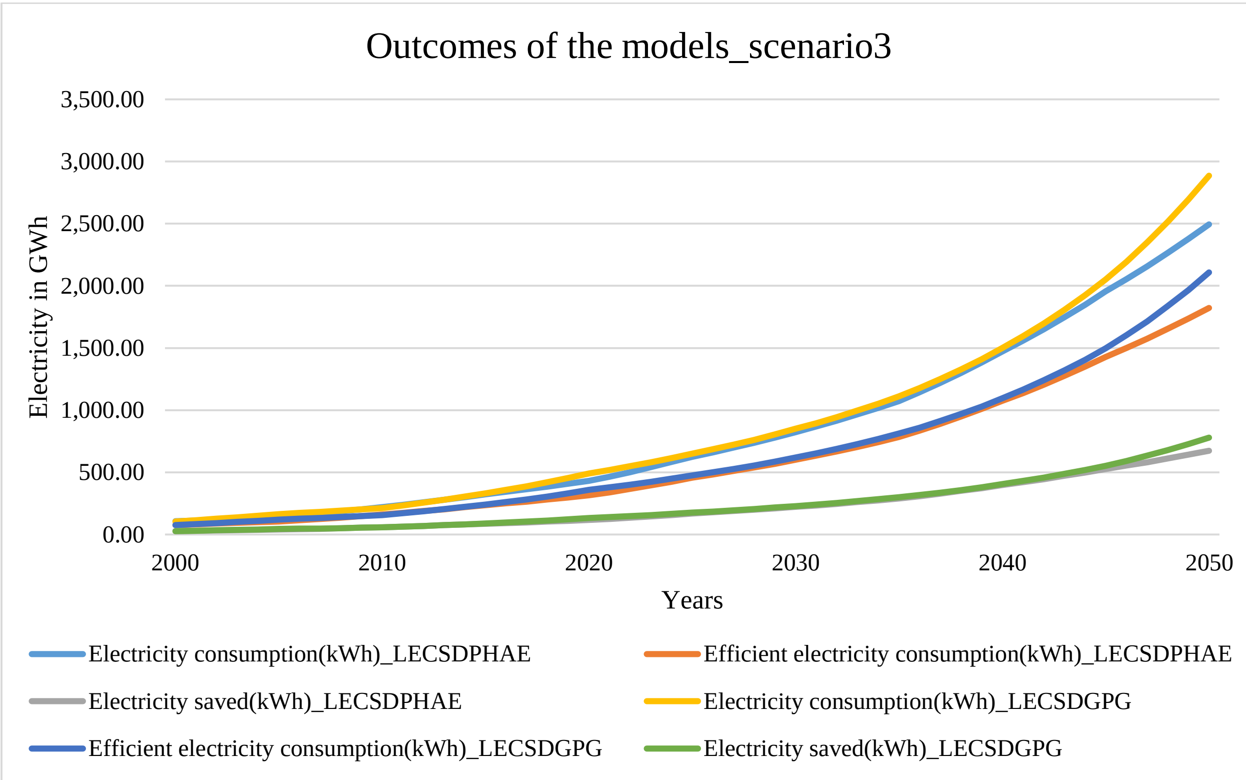


Figure 4-21:Outcome of the models_scenario3

4.7.4 Electricity saved

The simulation results of scenario2 and 3 revealed an important electricity savings through the years due to the dramatic energy efficiency measures introduced in the models. The energy savings trends can be seen in figures 4.14 and 4.14.

For scenario2: Specifically, in 2030 and 2050, the reduction in electricity consumption is expected to be 36.5GWh and 110.6GWh in the LECSDPHAE (Table A.8) model but for the LECSDGPG model the reduction is expected to be 36.4GWh and 120GWh (Table A.9). From 2018 to 2030, the total amount of energy saved is estimated to be 279GWh while the forecasted energy reduction in the horizon of 2050 is 1,751GWh with the LECSDGPG model. As for the LECSDPHAE model, 339GWh of the energy is projected to be saved from 2018 to 2030. Furthermore, the savings are even more pronounced if the time span is extended by twenty more years. The savings are estimated to be 1,734GWh from 2018 to 2050.

For scenario3: For this case, in 2030 and in 2050, the reduction in electricity consumption is expected to be 234GWh and 709GWh with the LECSDPHAE model (Table A.10) but for the LECSDGPG model, the reduction will be 233GWh and 768GWh (Table A.11). As it can be observed in the earlier figure 4.15 and 4.16, from 2018 to 2030, the total amount of energy saved is estimated to be 2,240GWh while the forecasted energy reduction in horizon 2050 is 11,216GWh with the LECSDGPG model. As for LECSDPHAE model, 2,171GWh of the energy is projected to be saved from 2018 to 2030. Furthermore, the savings are even pronounced if the time span is extended by twenty more years. The savings are estimated to be 11,110GWh from 2018 to 2050.

4.8 Carbon dioxide reduction

Energy efficiency is one of the ways to cutting greenhouse gas emissions. Although there is an open lack of consensus among scientists' community, GHG emissions are the most noticeable causes of Global Warming. The promotion of energy efficient appliances will surely lead to GHG reduction. Electricity consumed in Togo comes from various sources such as hydropower plants, thermal plants using diesel, Contour Global, etc. An assumption in energy savings from thermal plant and Contour Global would have a tremendous impact on the national GHG emissions. Therefore, the following analysis is focused on the reduction in carbon dioxide emissions in relation to electricity production from Diesel, heavy fuel oil and NG.

The implementation of energy efficiency policies stated in scenario_2 could help to reduce CO2 emissions up to 1) 7,362 tonnes from NG; 2) 9,724 tonnes from Diesel; 3) 10,157 tonnes from HFO by 2030. In addition, the estimated reductions from the LECSDPHAE model are: 1) 22,333tones from NG; 2) 29,499 tonnes from Diesel; and 3) 30,813 tonnes from HFO by 2050 9 (Table A.12).

According to the LECSDGPG model, the plausible reductions are: 1) 7,346 tonnes from NG; 2) 9,703tones from Diesel; and 10,135 tonnes from HFO by 2030. Also, this same model estimates the reductions to be: 1) 24,196tones from NG; 2) 31,959 tonnes from diesel; and 3) 33,382 tonnes from HFO by 2050 as can be seen in figure 4.18 and table A.15.

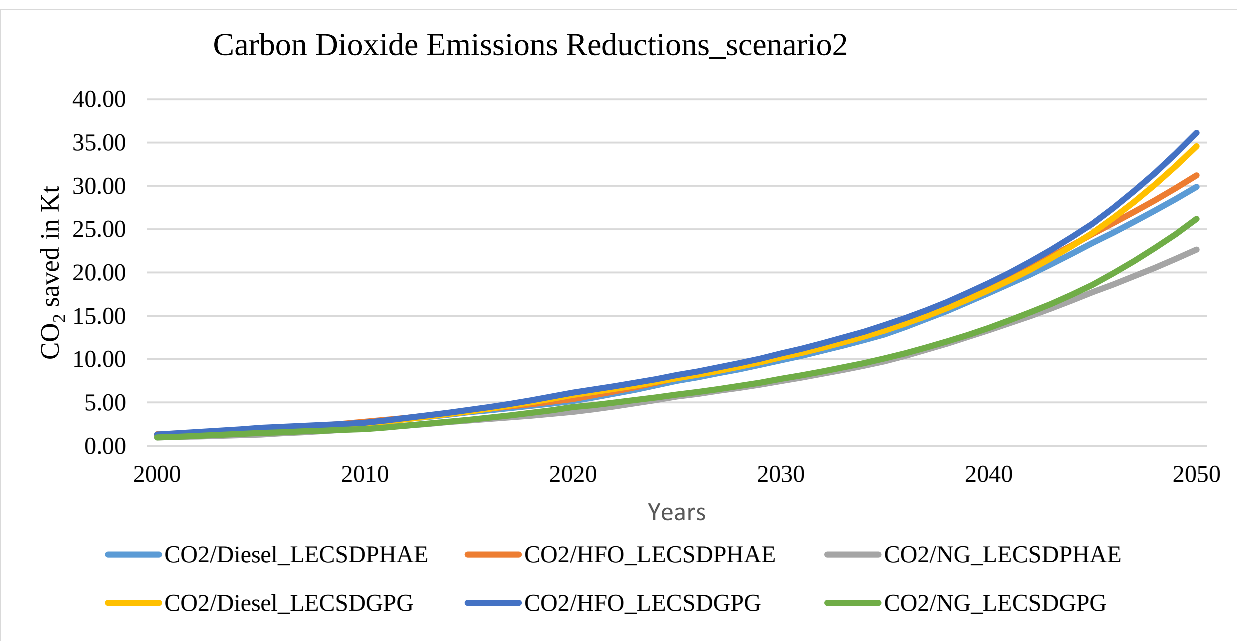


Figure 4-22:Carbon dioxide reductions_scenario2

Figure 4-22: Carbone dioxide reductions_scenario2

Alternatively, the implementation of energy efficiency measures as formulated in scenario_3 could help to reduce CO2 emissions up to: 1) 65,096 tonnes from HFO; 2) 47,182 tonnes from NG; and 3) 62,320 tonnes from Diesel by 2030. Also, the reductions in relation to NG, Diesel and HFO are estimated to be respectively 143,137 tones, 189,063 tones, and 197,483 tonnes from the LECSDPHAE model (Table A.13).

According to LECSDGPG model, the reductions could be: 1) 47,082 tonnes from NG; 2) 62,189 tonnes from Diesel; and 3) 64,958 tonnes from HFO by 2030. Extending the time frame to 2050, there is a significant increase in CO_2 reductions. The latter are 155,070 tonnes for NG, 204,826 tonnes for Diesel, and 213,947 tonnes for HFO (Table A.15). Figure 4.19 highlights the aforementioned reductions.

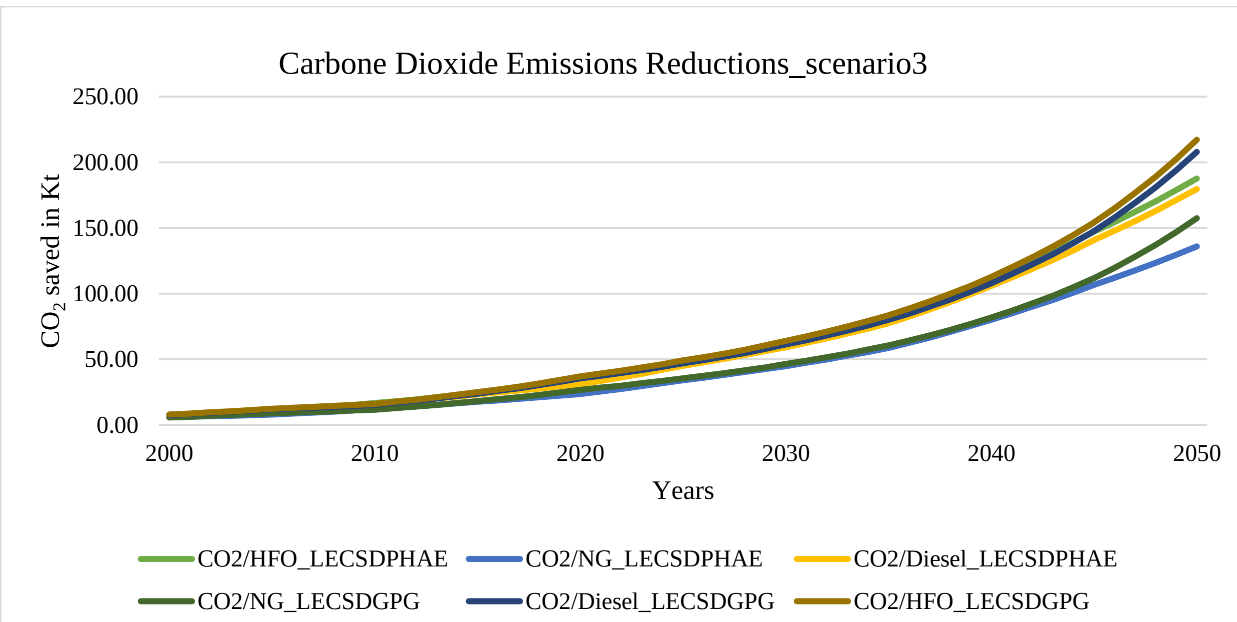


Figure 4-23:Carbon dioxide reductions_scenario3

4.9 Rebound Effect analysis

The rebound effect is a reduction that occurs in expected energy savings gained from new technologies and other measures that increase the efficiency of resource use by the changes in consumers' behaviour. For example, if 10% improvement in ventilator efficiency results in only a 6% drop in electricity consumption, there is a 40% rebound effect (since $^{(10-6)/10}$ = 40%). The missing 4% might have been consumed by using more the ventilator.

The rebound effect was first described by the English economist William Stanley Jevons. In 1865, he observed that the improvement in technology that increased the efficiency of coal-use led to the increased consumption of coal for many new uses. In the 1980s, economists Daniel Khazzoom and Leonard Brookes revisited the Jevons paradox for the case of society's energy consumption. They argued that increased energy efficiency paradoxically tends to lead to increased energy consumption. In 1992, the US economist Harry Saunders dubbed this hypothesis the Khazzoom–Brookes postulate. Saunders showed that it was true under neo-classical growth theory over a wide range of assumptions. The aforementioned postulate states that "increased energy efficiency at the microeconomic level while leading to a reduction of energy use at this level, leads not to a reduction, but instead to an increase in energy use, at the national, or macroeconomic level". This rebound effects have been the subject of intense debate in the field of energy efficiency policy for many years. Unfortunately, a few literatures deal with the subject in the developing countries. In the past, the debate has been focused on the perceived loss of the expected energy savings and related benefits resulting from this rebound effects.

Nonetheless, more recently, there has been a growing recognition that policymakers need to consider the health, economic and other non-energy benefits that often result from the increase in energy services as consequence of the rebound effects. This is especially true in developing countries. The basic energy service demands are often not being met such as lighting, heating, cooling, and refrigeration of food. The improvement of economic conditions and increase in household incomes leads to the increase in energy services such as space conditioning and appliances. This results in rapidly rise of energy demand trends (Can et al. 2015). The current study had touched on the subject. Therefore, it had been administrated a question in the survey to find out customers' behaviour. Would they purchase other appliances if it has been authorized or accepted only efficient appliances in Lomé's market? The analysis of the results gave 65.7% of "YES" as seen in Table 4.16.

Table 4-16Case summary of rebound effect

Cases					
Valid		Missing		Total	
N	Percent	N	Percent	N	Percent
159	65.70%	83	34.30%	242	100.00%

From that, the proportion of the type of appliances as seen in the latter table, some key figures were extracted and presented in Table 4.17, also highlighted in the figure 4.20. There would be a 25% increase of TV, 19% of freezers, and 18% of refrigerators, etc. in case of responses. These results signify that, in majority, people who do not have the above mentioned appliances would buy. Those who have already one would buy another. One can understand that there will be an improvement in Lomé's population's well-being.

Table 4-17:Rebound effect on appliances frequencies

		Responses		Percent of Cases
		N	Percent	
Households appliances to buy	TV	89	25.20%	56.00%
	Refrigerator	62	17.60%	39.00%
	Freezer	67	19.00%	42.10%
	air-conditioner	22	6.20%	13.80%
	Fan	45	12.70%	28.30%
	Brewer	20	5.70%	12.60%
	Electric cooker	44	12.50%	27.70%
	Other	4	1.10%	2.50%
Total		353	100.00%	222.00%

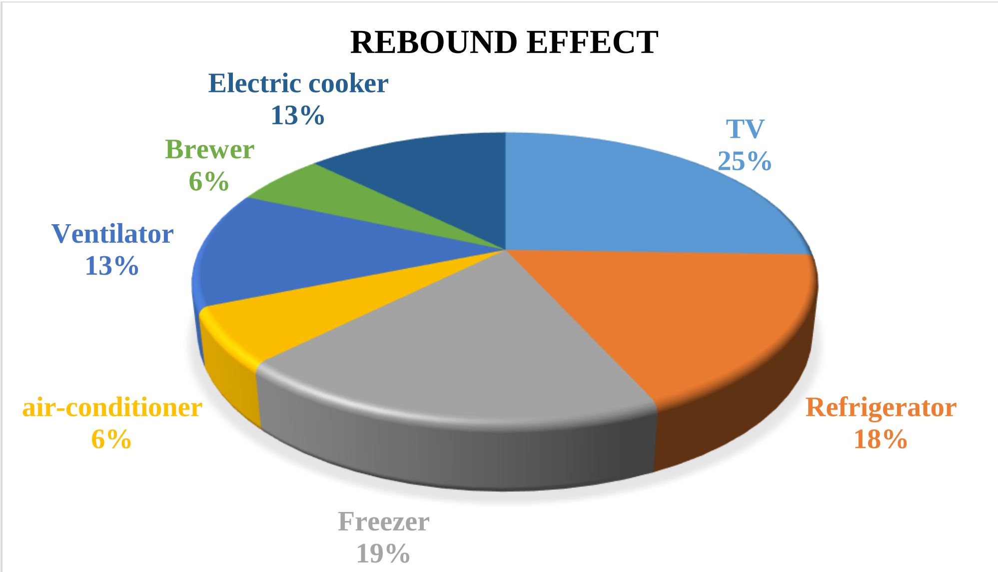


Figure 4-24:Increase of appliances due to EE measure

Figure 4-24: Increase of appliances due to EE measure

The corresponding electricity consumption was estimated and presented in the figure 4.21. In the increase of electricity consumption, the consumption related to freezers has the biggest share, i.e., 34.52% as compared to TV which consumption represents 21.57%, as presented in the figure 4.22. The electricity consumption due to the rebound effect represents 34.93%.

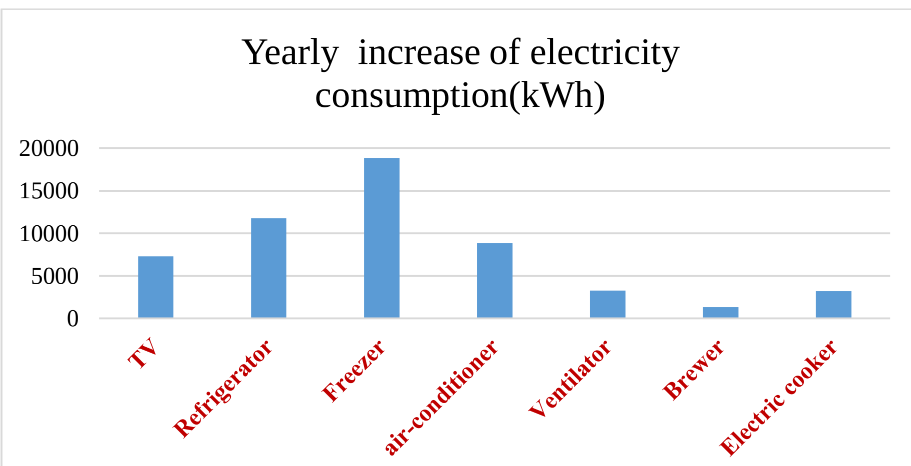


Figure 4-25:Increase of electricity consumption per appliances due to EE measures

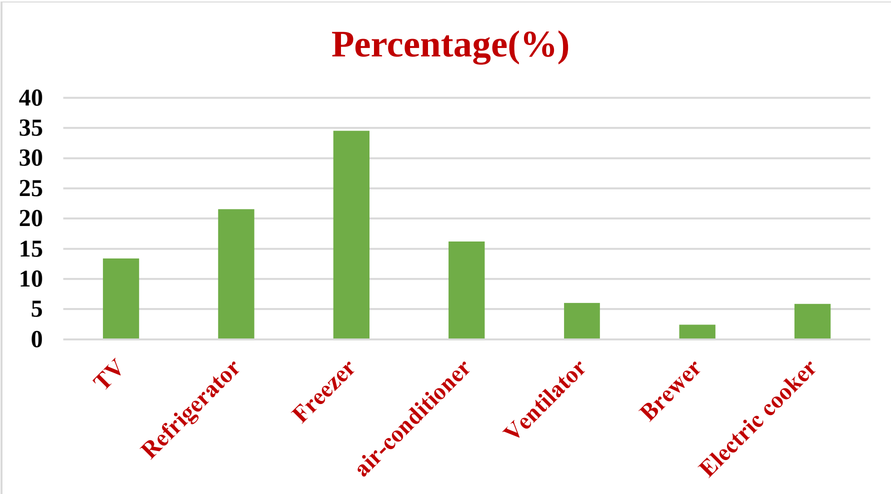


Figure 4-26:: Percentage of increase of electricity consumption per type of appliance

Due to the rebound effect, the increase in electricity consumption in Lomé's households would be 34.93%. It can be understood that the improvement of energy efficient policies will lead to the improvement of the quality of live in Lomé. In consideration of the goal stated as 'Energy for All', the country has to produce or look for an additional energy in order to improve the well-being of the population. The good news is that the implementation of efficient measures would constitute an additional less cost source of energy for the country. This could alleviate the population's need of energy.

5 CONCLUSION AND RECOMMANDATION

5.1 CONCLUSION

The main objective of this study is to assess the potential of energy efficiency in the residential sector in Lomé, the capital city of Togo. Also, the corresponding CO_2 emissions' reduction, by the horizon of 2050 under different energy efficiency scenarios, was investigated. To attain this objective, several approaches and assumptions were implemented.

To estimate the long-term electricity consumption in Lomé's residential sector, a system dynamic, SD, modelling was selected. Two different models of the household electricity consumption of Lomé were developed. The first model (LECSDGPG) has population, GDP and per capita electricity consumption as principal variables, while the second model (LECSDPHE) has population, houses with access to electricity, and the number of households having access to electricity as variables. These models were calibrated and validated using raw data for the past sixteen years (2000-2016). The models were qualified as very good with a correlation coefficient of 0.992 for the LECSDPHE model and 0.983 for LECSDGPG model. It can be realized from this study that system dynamics, SD, is a powerful and valuable approach in estimating long-term electricity consumption. Therefore, the electricity consumption in Lomé's households could be simulated from the present time to near future (the year 2030) and to the far future (2050). The population, GDP, per capita electricity consumption, number of houses having access to electricity and household appliances' efficiency effects data were utilized in this research.

Also, a random 242 sample households were surveyed in order to assess appliances and light fixture in Lomé. It was found that numerous light fixtures and appliances were used in Lomé's residential sector. The most common lights fixtures revealed through this study were: 1) Fluorescent lamps (49.7%), 2) Neon lamps (34.9%), 3) LED lamps (8%), and 4) Incandescent bulbs (2.4%). Moreover, the proportion of the most frequent household appliances found were: 1) televisions (TV) (97.1%), 2) ventilators (66.94%), refrigerator (18.6%), 3) brewers (17.8%) 4) Freezers (16.9%), 5) air conditioner (3.3%), 6) and 7) Electric Cooker (1.7%). Thus, the current drivers of electricity consumption are television, freezers, brewers, ventilators and lamps. The survey also revealed a high presence of used televisions, refrigerators, freezers, brewers and ventilators in Lomé. Also, it is worthwhile to point out that, in Lomé, it can be found five different socio-economic households on the base of light fixtures and appliances possession.

An experiment was set up and carried out on two TVs and refrigerators-freezers to estimate the difference in electricity consumption between used and brand new appliances for one month. The results showed that the used television consumes 0.24Wh more than the newly bought one TV. In addition, the used refrigerator-freezer consumes 12Wh more than the new brand appliance.

Furthermore, the study was carried under three energy-efficiency policy scenarios: 1) Business-As-Usual (BAU), 2) the proposed energy-efficiency policy, which specifies that incandescent light bulbs and used appliances are banned in Lomé, and 3) the extreme (sensitivity) case, which specifies that only household appliances fitting a specific margin of rated power are accepted in Lomé. The latter scenario includes the assumption made in the scenario (2). The related percent of electricity reduction due to the energy-efficient policy are 4.4% and 28% under scenarios (2) and (3), respectively. As a result, the following can be found:

a) The population in Lomé under the current birth-rate, will be close to 3 million in 2030 and 5 million in 2050.
b) With the ongoing development, Togo's per capita electricity consumption is estimated to be 199 kWh in 2030 and 250 kWh in 2050. This fact creates a self-re-enforced loop. This will further drive the future electricity consumption in Lomé's residential sector resulting in an increase close to 830GWh in 2030 and 2.7TWh in 2050 with regard to the growing economy of Togo.
c) Regarding the growing households having access to electricity, the consumption of electricity will be close to 830GWh in 2030 and 2.5TWh in 2050.
d) Under the scenario2, the predicted electricity savings would be close to 40GWh in 2030 and 115GWh in 2050 with the LECSDPHE model. Under this same scenario, this energy savings for the LECSDGPG model would be approximatively 40GWh in 2030 and 120GWh in 2050. Under the scenario3, it is predicted that the electricity savings would be 234GWh in 2030 and 708GWh in 2050 with the LECSDPHE model. Also. Under the latter model and scenario, the energy savings are predicted to be close 233GWh in 2030 and 768GWh in 2050.
e) Under ideal conditions, the economy on electricity under these scenarios may imply reduction in CO_2 emissions. It should be pointed out that the expected electricity savings will be undermined by any expensive utilization of NG, diesel fuel and heavy fuel oil (HFO) as the main combustibles.

f) Under scenario2, the reductions in CO_2 is predicted to be 7.3 kilotons from NG, 9.72 kilotons from Diesel fuel and 10.2 kilotons from HFO in 2030. The reductions then become 22 kilotons from NG, 29 kilotons from Diesel fuel and 31 kilotons from HFO in 2050, respectively in the LECSDPHAE model.

g) Also, under the LECSDGPG model, the aforementioned reductions will be 7.35 kilotons from NG, 9.70 kilotons from Diesel fuel and 10.60 kilotons from HFO for the year 2030; and 24 kilotons from NG, 32 kilotons from diesel fuel and 34 kilotons from heavy fuel oil (HFO) in 2050.

h) Under the scenario3, the expected reductions in CO_2 emissions is foreseen to be 65 kilotons from HFO, 47 kilotons from NG, and 62 kilotons from Diesel fuel in 2030. In 2050, these reductions will be for NG, Diesel fuel and HFO 143 kilotons, 189 kilotons and 198 kilotons, respectively in the LECSDPHAE model.

i) According to the LECSDGPG model, the reductions are expected to be 47 kilotons from NG, 62 kilotons from diesel fuel and 65 kilotons from HFO in 2030. These reductions then will become, in 2050, respectively 155 kilotons, 204 kilotons, and 214 kilotons.

The study has considered briefly the rebound effect because in practical life there may be a reduction on the expected electricity savings. It is a fact that in emerging economies, basic energy service demands, such as lighting, heating, cooling, and refrigeration of food are often not being met. Thus, the rebound effect can be understood as a contribution of improving both the quality of life and the national economy for the benefit of the residents.

Nevertheless, the study presents some limits. First, the actual number of households with electricity could not be found. Hence, an assumption was made and that could alter the accuracy of the results. Second, the appliances from the same brand and same rated power were not available and not easy to determine for the experiments. Third, the present and future weather parameters could not be considered, such as temperature and heat waves. The latter variables were absent in the estimation of the electricity consumption; thus their true impacts could not be highlighted.

5.2 RECOMMENDATIONS

At the end of this research, we found that it would be useful to set up and implement the following policies.

- Efficiency standard programs: Two levels of efficiency, ‘‘target’’ and ‘‘minimum,’’ must be designed for various energy consumption appliances, such as refrigerators, air-conditioners, televisions, brewers, ventilators and light fixtures. The target level efficiency is the level that must be attained by the end of year 2022. The purpose of the level should be to reduce the current electricity consumption by a certain percentage. The minimum level efficiency is level that must be attained before the target year. The purpose of the level will be to reduce the current electricity consumption by up to a certain percentage. This will be achieved by allowing only the energy-efficient equipment in the Togolese’s market. This program is recommended to target both the giant importers and the retailers. As a result, it is recommended that the residential consumers would be provided with the necessary guidance needed to purchase any of household appliances of their choice.
- Efficiency labelling program: Labelling of energy consumption efficiency is required for all household appliances, and light fixtures. The current importers and the future domestic manufacturers are required to get designated products: 1) tested by authorized testing agencies and 2) specified the test results on the products. Energy consumption efficiency and efficient usage must be mentioned when advertised
- Rating-labelling program: Labelling of relative ratings of energy consumption efficiency are required for residential appliances and all light fixtures. The testing agencies should analyse and choose an interval of rated power for each appliance.
- Market transformation: put-on efforts to transform successfully the market in order to increase the penetration of energy-efficiency equipment or other services into the marketplace.

In addition, we recommend to educate the residents to better understand the concepts of EE and to promote energy conservation by adopting good practices and behaviours, such as unplugging all the extension cords, unplugging all standby appliances to avoid any phantom load, and switching off all lights when the house and/or rooms are empty.

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Appendix

Appendix A

Additional tables

Table A.1: Historical data

Years	Households with access to electricity	Household electricity consumption
2000	54665.1	111334098.1
2001	58308.3	119152600.6
2002	65795.4	124812257.6
2003	71711.1	130471914.7
2004	74484	160353348.1
2005	78828.3	163854159.8
2006	83756.7	175494525.4
2007	87671.7	168774040.7
2008	94284	204865908.2
2009	100958.4	229609338.8
2010	110703.6	251575790.8
2011	124176.6	266885906.3
2012	130956.3	282174422.9
2013	141696	300300044.5
2014	158988.6	326082067.9
2015	174644.1	339906108.4
2016	193239.9	357572567.5

Table A.2: Lamps statistic

		Number of Neon bulbs	Number of Fluorescent bulbs	Number of Led bulbs	Number of Incandescent bulbs
N	Valid	130	186	43	8
	Missing	112	56	199	234
Mean		3.06	4.07	3.74	2.13
Median		2	2	3	1.5
Minimum		1	1	1	1
Maximum		20	20	12	6
Percentiles	25	1	1	1	1
	50	2	2	3	1.5
	75	4	6	6	2.75

Table A.3: Power of Lamps statistics

		Power of Neon	Power of Fluorescent	Power of led	Power of incandescent
N	Valid	129	185	43	8
	Missing	113	57	199	234
Mean		22.02	15.90	8.19	52.00
Median		20.00	15.00	9.00	60.00
Minimum		20	15	5	40
Maximum		40	40	9	60

Table A.4: Hours of usage per day

		Neon lamps	Fluorescent lamps	Led lamps	Incandescent lamps
N	Valid	130	186	43	8
	Missing	112	56	199	234
Mean		6.74	6.25	5.5	5.75
Median		6	5	4	5.5
Minimum		1	1	1	2
Maximum		24	20	24	12
Percentiles	25	4	4	4	3.25
	50	6	5	4	5.5
	75	8.75	8	6	7.5

Table A.5: Detailed summary on TV

		Responses		Percent of Cases
		N	Percent	
Marks of TV	LG	46	19.40%	21.80%
	SAMSUNG	39	16.50%	18.50%
	PHILIPPS	31	13.10%	14.70%
	SONY	19	8.00%	9.00%
	PRESIDENT	3	1.30%	1.40%
	GRUDING	7	3.00%	3.30%
	BEKO	1	0.40%	0.50%
	SHARP	35	14.80%	16.60%
	AUTRE	12	5.10%	5.70%
	X-TIGI	2	0.80%	0.90%
	UNIVERSAL	1	0.40%	0.50%

	TOSHIBA	2	0.80%	0.90%
	THOMSON	3	1.30%	1.40%
	STERLING	1	0.40%	0.50%
	SCHNIDER	1	0.40%	0.50%
	SANYO	1	0.40%	0.50%
	SABA	2	0.80%	0.90%
	ROAD STAR	1	0.40%	0.50%
	PROSONIC	1	0.40%	0.50%
	PANASONIC	1	0.40%	0.50%
	ORION	1	0.40%	0.50%
	ONWA	1	0.40%	0.50%
	NOCK	1	0.40%	0.50%
	NEON	1	0.40%	0.50%
	MIVAR	2	0.80%	0.90%
	LEWAX	1	0.40%	0.50%
	LEADER	1	0.40%	0.50%
	JVC	1	0.40%	0.50%
	ITT	1	0.40%	0.50%
	INSUGNIA	1	0.40%	0.50%
	INNO	1	0.40%	0.50%
	GOLD	1	0.40%	0.50%
	FUNKEN	2	0.80%	0.90%
	ENOKY	1	0.40%	0.50%
	DIGITAL	1	0.40%	0.50%
	DAEWOO	2	0.80%	0.90%
	CONTINENTAL	1	0.40%	0.50%
	CIRRADIA	1	0.40%	0.50%
	BERON	1	0.40%	0.50%
	BERRAN	3	1.30%	1.40%
	ARISTONA	1	0.40%	0.50%
	WORLDOFVISION	1	0.40%	0.50%
	WEBE	1	0.40%	0.50%
Total		237	100.00%	112.30%

Table A.6: Age of televisions

		Number of years of TV LG	Number of Years of TV SAMSUNG	Number of years of TV PHILIPPS	Number of years of TV SONY	Number of years of TV PRESIDENT	Number of years of TV GRUDING	Numbers years of TV BEKO	Numbers years of TV SHARP	Numbers years of TV other
N	Valid	45	39	30	20	3	7	1	33	53
	Missing	197	203	212	222	239	235	241	209	189
Mean		4.76	4.38	5.9	5.4	3.67	4	1	5.48	4.53
Median		3	3	3	4	3	2	1	5	3
Minimum		1	1	1	1	3	1	1	1	1
Maximum		17	17	35	15	5	11	1	15	30
Percentiles	25	2	2	1	3	3	2	1	3.5	1
	50	3	3	3	4	3	2	1	5	3
	75	5.5	6	6	7	5	7	1	8	5

Table A.7: Age of air conditioners

		ROYAL AIR	SHARP	ICE_CRIME	CLIMY
N	Valid	4	2	1	1
	Missing	238	240	241	241
Mean		3.5	4.5	20	3
Median		3	4.5	20	3

Table A.8: Trends of electricity consumption and Energy saving 2050(LECSDPHAE_Scenario2)

Years	Electricity consumption(kWh)	Efficient Electricity consumption(kWh)	Electricity saved(kWh)
2016	345,631,343.47	330,423,564.36	15,207,779.11
2017	366,255,749.43	350,140,496.45	16,115,252.97
2018	387,931,521.77	370,862,534.82	17,068,986.96
2019	410,706,343.51	392,635,264.40	18,071,079.11
2020	434,629,891.39	415,506,176.17	19,123,715.22
2021	469,232,860.00	448,586,614.16	20,646,245.84
2022	506,002,201.43	483,738,104.57	22,264,096.86
2023	545,049,046.51	521,066,888.46	23,982,158.05
2024	586,489,554.58	560,684,014.18	25,805,540.40
2025	630,445,122.89	602,705,537.48	27,739,585.41
2026	666,407,478.81	637,085,549.74	29,321,929.07
2027	704,110,365.77	673,129,509.68	30,980,856.09
2028	743,629,622.44	710,909,919.05	32,719,703.39
2029	785,044,164.69	750,502,221.44	34,541,943.25
2030	828,436,104.22	791,984,915.63	36,451,188.59
2031	874,382,724.31	835,909,884.44	38,472,839.87
2032	922,572,275.78	881,979,095.65	40,593,180.13
2033	973,103,834.79	930,287,266.06	42,816,568.73
2034	1,026,080,549.21	980,933,005.05	45,147,544.17
2035	1,081,609,797.35	1,034,018,966.26	47,590,831.08
2036	1,153,469,462.76	1,102,716,806.40	50,752,656.36
2037	1,229,251,941.83	1,175,164,856.39	54,087,085.44
2038	1,309,142,779.80	1,251,540,497.49	57,602,282.31
2039	1,393,335,496.60	1,332,028,734.75	61,306,761.85
2040	1,482,031,907.63	1,416,822,503.69	65,209,403.94
2041	1,570,097,421.37	1,501,013,134.83	69,084,286.54
2042	1,662,674,099.75	1,589,516,439.36	73,157,660.39
2043	1,759,967,568.63	1,682,528,995.61	77,438,573.02

2044	1,862,192,086.89	1,780,255,635.06	81,936,451.82
2045	1,969,570,888.09	1,882,909,769.02	86,661,119.08
2046	2,068,882,110.25	1,977,851,297.40	91,030,812.85
2047	2,172,712,514.88	2,077,113,164.23	95,599,350.65
2048	2,281,252,225.50	2,180,877,127.57	100,375,097.92
2049	2,394,698,911.90	2,289,332,159.78	105,366,752.12
2050	2,513,258,076.89	2,402,674,721.50	110,583,355.38

Table A.9: Trends of electricity consumption and Energy saving to 2050 (LECSDGPG_Scenario2)

Years	Electricity consumption(kWh)	Efficient Electricity consumption(kWh)	Electricity saved(kWh)
2016	355,352,070.11	339,716,579.02	15,635,491.08
2017	384,142,047.94	367,239,797.83	16,902,250.11
2018	415,151,147.06	396,884,496.59	18,266,650.47
2019	448,591,057.03	428,853,050.52	19,738,006.51
2020	484,695,598.91	463,368,992.56	21,326,606.35
2021	511,711,825.63	489,196,505.30	22,515,320.33
2022	540,464,710.40	516,684,263.14	23,780,447.26
2023	571,080,525.00	545,952,981.90	25,127,543.10
2024	603,695,675.07	577,133,065.37	26,562,609.70
2025	638,457,579.98	610,365,446.46	28,092,133.52
2026	670,648,069.64	641,139,554.57	29,508,515.06
2027	705,330,825.48	674,296,269.16	31,034,556.32
2028	742,729,945.75	710,049,828.13	32,680,117.61
2029	783,093,024.56	748,636,931.48	34,456,093.08
2030	826,693,847.99	790,319,318.68	36,374,529.31
2031	869,843,908.23	831,570,776.27	38,273,131.96
2032	915,783,139.28	875,488,681.15	40,294,458.13
2033	964,717,550.18	922,269,977.97	42,447,572.21
2034	1,016,869,929.37	972,127,652.48	44,742,276.89
2035	1,072,481,317.06	1,025,292,139.11	47,189,177.95
2036	1,134,809,877.98	1,084,878,243.35	49,931,634.63
2037	1,201,869,270.36	1,148,987,022.46	52,882,247.90
2038	1,274,074,306.05	1,218,015,036.59	56,059,269.47
2039	1,351,880,364.92	1,292,397,628.86	59,482,736.06
2040	1,435,787,697.67	1,372,613,038.98	63,174,658.70
2041	1,524,337,155.04	1,457,266,320.22	67,070,834.82
2042	1,619,217,824.98	1,547,972,240.68	71,245,584.30
2043	1,720,930,534.49	1,645,209,590.97	75,720,943.52

2044	1,830,018,824.49	1,749,497,996.21	80,520,828.28
2045	1,947,072,818.37	1,861,401,614.37	85,671,204.01
2046	2,080,956,082.04	1,989,394,014.43	91,562,067.61
2047	2,224,679,093.69	2,126,793,213.57	97,885,880.12
2048	2,379,001,416.21	2,274,325,353.89	104,676,062.31
2049	2,544,743,540.50	2,432,774,824.72	111,968,715.78
2050	2,722,791,932.56	2,602,989,087.53	119,802,845.03

Table A.10: Trends of electricity consumption and saved up to 2050 (LECSDPHAE_Scenario3)

Years	Electricity consumption(kWh)	Efficient Electricity consumption(kWh)	Electricity saved(kWh)
2016	345,631,343.47	248,163,304.61	97,468,038.86
2017	366,255,749.43	262,971,628.09	103,284,121.34
2018	387,931,521.77	278,534,832.63	109,396,689.14
2019	410,706,343.51	294,887,154.64	115,819,188.87
2020	434,629,891.39	312,064,262.02	122,565,629.37
2021	469,232,860.00	336,909,193.48	132,323,666.52
2022	506,002,201.43	363,309,580.63	142,692,620.80
2023	545,049,046.51	391,345,215.39	153,703,831.12
2024	586,489,554.58	421,099,500.19	165,390,054.39
2025	630,445,122.89	452,659,598.23	177,785,524.65
2026	666,407,478.81	478,480,569.79	187,926,909.02
2027	704,110,365.77	505,551,242.62	198,559,123.15
2028	743,629,622.44	533,926,068.91	209,703,553.53
2029	785,044,164.69	563,661,710.24	221,382,454.44
2030	828,436,104.22	594,817,122.83	233,618,981.39
2031	874,382,724.31	627,806,796.06	246,575,928.26
2032	922,572,275.78	662,406,894.01	260,165,381.77
2033	973,103,834.79	698,688,553.38	274,415,281.41
2034	1,026,080,549.21	736,725,834.33	289,354,714.88
2035	1,081,609,797.35	776,595,834.50	305,013,962.85
2036	1,153,469,462.76	828,191,074.26	325,278,388.50
2037	1,229,251,941.83	882,602,894.24	346,649,047.60
2038	1,309,142,779.80	939,964,515.89	369,178,263.90
2039	1,393,335,496.60	1,000,414,886.56	392,920,610.04
2040	1,482,031,907.63	1,064,098,909.67	417,932,997.95
2041	1,570,097,421.37	1,127,329,948.54	442,767,472.83
2042	1,662,674,099.75	1,193,800,003.62	468,874,096.13
2043	1,759,967,568.63	1,263,656,714.27	496,310,854.35
2044	1,862,192,086.89	1,337,053,918.38	525,138,168.50

2045	1,969,570,888.09	1,414,151,897.65	555,418,990.44
2046	2,068,882,110.25	1,485,457,355.16	583,424,755.09
2047	2,172,712,514.88	1,560,007,585.69	612,704,929.20
2048	2,281,252,225.50	1,637,939,097.91	643,313,127.59
2049	2,394,698,911.90	1,719,393,818.74	675,305,093.16
2050	2,513,258,076.89	1,804,519,299.20	708,738,777.68

Table A.11: Trends of electricity consumption and saved up to 2050(LECSDGPG_Scenario3)

Years	Electricity consumption(kWh)	Efficient Electricity consumption(kWh)	Electricity saved(kWh)
2016	355,352,070.11	255,142,786.34	100,209,283.77
2017	384,142,047.94	275,813,990.42	108,328,057.52
2018	415,151,147.06	298,078,523.59	117,072,623.47
2019	448,591,057.03	322,088,378.95	126,502,678.08
2020	484,695,598.91	348,011,440.02	136,684,158.89
2021	511,711,825.63	367,409,090.80	144,302,734.83
2022	540,464,710.40	388,053,662.07	152,411,048.33
2023	571,080,525.00	410,035,816.95	161,044,708.05
2024	603,695,675.07	433,453,494.70	170,242,180.37
2025	638,457,579.98	458,412,542.42	180,045,037.55
2026	670,648,069.64	481,525,314.00	189,122,755.64
2027	705,330,825.48	506,427,532.69	198,903,292.79
2028	742,729,945.75	533,280,101.05	209,449,844.70
2029	783,093,024.56	562,260,791.63	220,832,232.93
2030	826,693,847.99	593,566,182.86	233,127,665.13
2031	869,843,908.23	624,547,926.11	245,295,982.12
2032	915,783,139.28	657,532,294.00	258,250,845.28
2033	964,717,550.18	692,667,201.03	272,050,349.15
2034	1,016,869,929.37	730,112,609.29	286,757,320.08
2035	1,072,481,317.06	770,041,585.65	302,439,731.41
2036	1,134,809,877.98	814,793,492.39	320,016,385.59
2037	1,201,869,270.36	862,942,136.12	338,927,134.24
2038	1,274,074,306.05	914,785,351.75	359,288,954.31
2039	1,351,880,364.92	970,650,102.01	381,230,262.91
2040	1,435,787,697.67	1,030,895,566.93	404,892,130.74
2041	1,524,337,155.04	1,094,474,077.32	429,863,077.72
2042	1,619,217,824.98	1,162,598,398.33	456,619,426.64
2043	1,720,930,534.49	1,235,628,123.76	485,302,410.73
2044	1,830,018,824.49	1,313,953,515.98	516,065,308.51
2045	1,947,072,818.37	1,397,998,283.59	549,074,534.78

2046	2,080,956,082.04	1,494,126,466.90	586,829,615.13
2047	2,224,679,093.69	1,597,319,589.27	627,359,504.42
2048	2,379,001,416.21	1,708,123,016.84	670,878,399.37
2049	2,544,743,540.50	1,827,125,862.08	717,617,678.42
2050	2,722,791,932.56	1,954,964,607.58	767,827,324.98

Table A.12: CO2 emission reduction from Diesel, HFO and NG under scenario2_LECSDPHAE model

Years	CO2 reduced from NG	CO2 reduced from Diesel	CO2 reduced from HFO
2016	3,071.36	4,056.83	4,237.50
2017	3,254.64	4,298.90	4,490.35
2018	3,447.25	4,553.32	4,756.10
2019	3,649.64	4,820.64	5,035.33
2020	3,862.23	5,101.44	5,328.63
2021	4,169.72	5,507.59	5,752.87
2022	4,496.46	5,939.17	6,203.67
2023	4,843.44	6,397.48	6,682.39
2024	5,211.69	6,883.89	7,190.46
2025	5,602.29	7,399.81	7,729.36
2026	5,921.86	7,821.92	8,170.26
2027	6,256.89	8,264.45	8,632.51
2028	6,608.07	8,728.31	9,117.02
2029	6,976.09	9,214.41	9,624.77
2030	7,361.68	9,723.72	10,156.76
2031	7,769.97	10,263.01	10,720.07
2032	8,198.20	10,828.64	11,310.88
2033	8,647.23	11,421.75	11,930.41
2034	9,118.00	12,043.56	12,579.91
2035	9,611.44	12,695.33	13,260.71
2036	10,250.01	13,538.78	14,141.72
2037	10,923.43	14,428.27	15,070.83
2038	11,633.36	15,365.98	16,050.30
2039	12,381.51	16,354.19	17,082.52
2040	13,169.69	17,395.26	18,169.95
2041	13,952.26	18,428.92	19,249.65
2042	14,774.92	19,515.54	20,384.65
2043	15,639.49	20,657.51	21,577.48
2044	16,547.89	21,857.37	22,830.77
2045	17,502.08	23,117.72	24,147.25
2046	18,384.58	24,283.38	25,364.83
2047	19,307.24	25,502.08	26,637.80
2048	20,271.75	26,776.06	27,968.52

2049	21,279.87	28,107.63	29,359.39
2050	22,333.41	29,499.22	30,812.95

Table A.13: CO_2 emission reduction from Diesel, HFO and NG under scenario3_LECSDPHAE model

Years	CO_2 reduced from NG	CO_2 reduced from Diesel	CO_2 reduced from HFO
2016	19,684.64	26,000.57	27,158.49
2017	20,859.26	27,552.07	28,779.09
2018	22,093.76	29,182.66	30,482.29
2019	23,390.84	30,895.93	32,271.86
2020	24,753.35	32,695.61	34,151.69
2021	26,724.09	35,298.66	36,870.67
2022	28,818.20	38,064.68	39,759.87
2023	31,042.03	41,002.03	42,828.04
2024	33,402.18	44,119.45	46,084.28
2025	35,905.56	47,426.07	49,538.16
2026	37,953.72	50,131.38	52,363.95
2027	40,101.00	52,967.63	55,326.51
2028	42,351.73	55,940.52	58,431.80
2029	44,710.40	59,055.98	61,686.01
2030	47,181.69	62,320.20	65,095.59
2031	49,798.47	65,776.59	68,705.92
2032	52,543.00	69,401.72	72,492.48
2033	55,420.91	73,203.02	76,463.07
2034	58,438.08	77,188.26	80,625.80
2035	61,600.62	81,365.52	84,989.09
2036	65,693.22	86,771.26	90,635.57
2037	70,009.24	92,472.10	96,590.29
2038	74,559.24	98,481.99	102,867.83
2039	79,354.25	104,815.50	109,483.40
2040	84,405.75	111,487.81	116,452.85
2041	89,421.32	118,112.65	123,372.73
2042	94,693.81	125,076.85	130,647.08
2043	100,234.94	132,395.88	138,292.06
2044	106,056.90	140,085.86	146,324.50
2045	112,172.42	148,163.57	154,761.95
2046	117,828.46	155,634.39	162,565.47
2047	123,741.89	163,445.17	170,724.10
2048	129,923.52	171,610.21	179,252.77
2049	136,384.62	180,144.39	188,167.01

2050	143,136.88	189,063.15	197,482.97

Table A.14: CO_2 emission reduction from Diesel, HFO and NG under scenario2_LECSDGPG model

Years	CO_2 reduced from NG	CO_2 reduced from Diesel	CO_2 reduced from HFO
2016	3,157.74	4,170.92	4,356.67
2017	3,413.58	4,508.84	4,709.64
2018	3,689.13	4,872.81	5,089.82
2019	3,986.29	5,265.31	5,499.80
2020	4,307.12	5,689.09	5,942.45
2021	4,547.19	6,006.19	6,273.67
2022	4,802.70	6,343.67	6,626.18
2023	5,074.76	6,703.02	7,001.54
2024	5,364.58	7,085.84	7,401.41
2025	5,673.49	7,493.86	7,827.59
2026	5,959.54	7,871.69	8,222.25
2027	6,267.74	8,278.78	8,647.47
2028	6,600.08	8,717.75	9,105.99
2029	6,958.75	9,191.51	9,600.85
2030	7,346.20	9,703.27	10,135.40
2031	7,729.64	10,209.74	10,664.43
2032	8,137.87	10,748.95	11,227.65
2033	8,572.71	11,323.31	11,827.59
2034	9,036.15	11,935.45	12,466.99
2035	9,530.33	12,588.19	13,148.79
2036	10,084.19	13,319.76	13,912.95
2037	10,680.10	14,106.87	14,735.11
2038	11,321.73	14,954.37	15,620.35
2039	12,013.13	15,867.61	16,574.27
2040	12,758.75	16,852.47	17,602.99
2041	13,545.63	17,891.82	18,688.62
2042	14,388.76	19,005.47	19,851.87
2043	15,292.60	20,199.32	21,098.88
2044	16,261.99	21,479.74	22,436.32
2045	17,302.16	22,853.65	23,871.42
2046	18,491.88	24,425.10	25,512.85
2047	19,769.03	26,112.04	27,274.92
2048	21,140.38	27,923.39	29,166.94
2049	22,613.20	29,868.77	31,198.96

2050	24,195.38	31,958.61	33,381.86

Table A.15: CO_2 emission reduction from Diesel, HFO and NG under scenario3_LECSDGPG model

Years	CO_2 reduced from Diesel	CO_2 reduced from HFO	CO_2 reduced from NG
2016	26,731.83	27,922.31	20,238.27
2017	28,897.59	30,184.53	21,877.93
2018	31,230.29	32,621.12	23,643.99
2019	33,745.85	35,248.71	25,548.48
2020	36,461.87	38,085.67	27,604.73
2021	38,494.20	40,208.51	29,143.38
2022	40,657.17	42,467.81	30,780.94
2023	42,960.29	44,873.50	32,524.59
2024	45,413.80	47,436.28	34,382.11
2025	48,028.81	50,167.75	36,361.90
2026	50,450.39	52,697.16	38,195.23
2027	53,059.44	55,422.41	40,170.51
2028	55,872.84	58,361.10	42,300.49
2029	58,909.21	61,532.69	44,599.28
2030	62,189.14	64,958.69	47,082.46
2031	65,435.16	68,349.27	49,539.98
2032	68,890.99	71,959.01	52,156.34
2033	72,572.15	75,804.11	54,943.29
2034	76,495.38	79,902.06	57,913.51
2035	80,678.82	84,271.81	61,080.73
2036	85,367.57	89,169.36	64,630.51
2037	90,412.20	94,438.66	68,449.72
2038	95,843.92	100,112.27	72,562.00
2039	101,696.98	106,226.00	76,993.26
2040	108,009.02	112,819.14	81,772.01
2041	114,670.27	119,777.05	86,815.15
2042	121,807.80	127,232.44	92,218.86
2043	129,459.27	135,224.66	98,011.67
2044	137,665.58	143,796.44	104,224.55
2045	146,471.12	152,994.13	110,891.09
2046	156,542.67	163,514.20	118,516.11
2047	167,354.42	174,807.45	126,701.52
2048	178,963.52	186,933.56	135,490.60
2049	191,431.69	199,956.99	144,930.07
2050	204,825.62	213,947.40	155,070.41

Appendix B

Additional figures

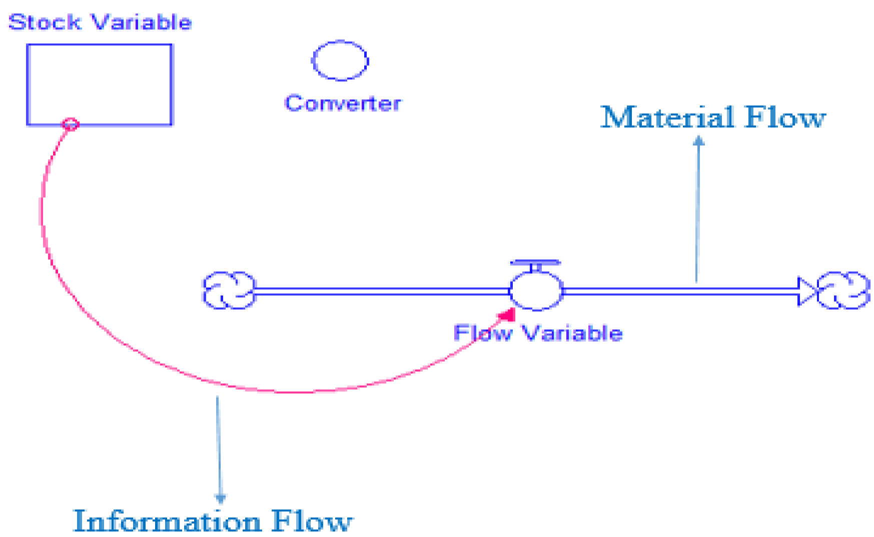

Figure B.1: Graphical representation of building blocks

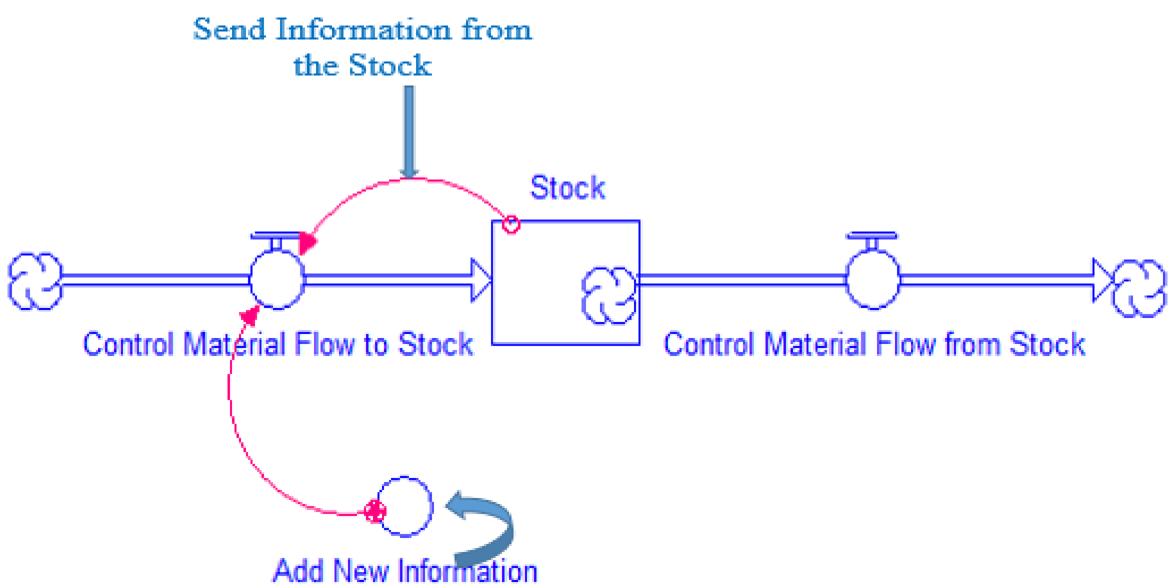

Figure B.2: Basic elements, adapted from slideplayer.com

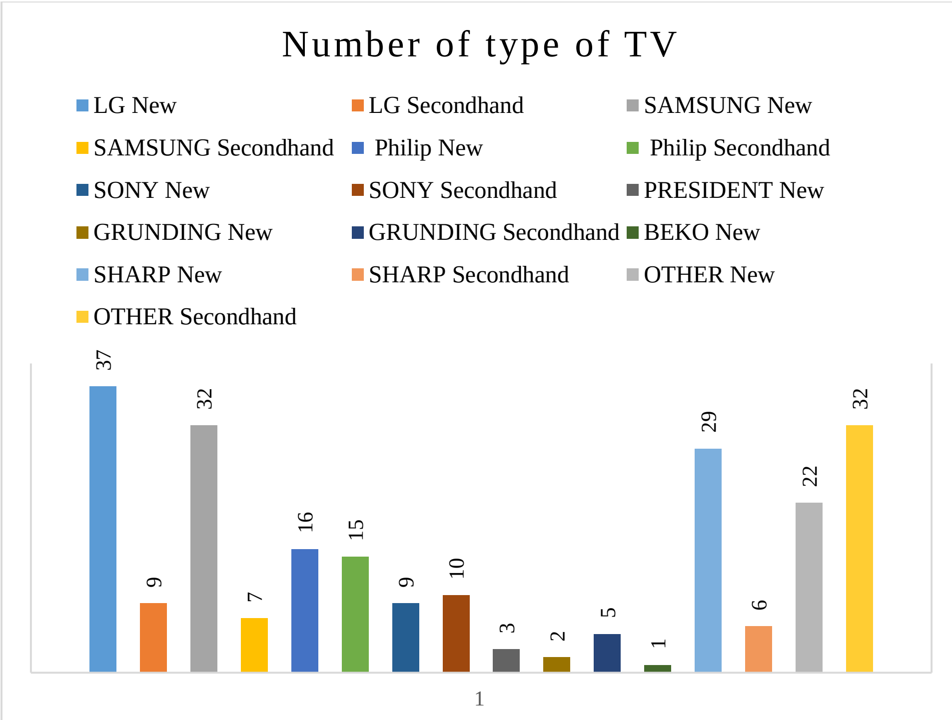

Figure B.3: Number of type of TV

Appendix C

Survey questionnaire

ENERGY EFFICIENCY STUDY IN TOGO

Supervisor code						Interviewer Code						Questionnaire no				

Zone: 1. Lomé Urban District 2. Golfe District: ______________________________

Introduction**:** Hello / Good evening, my name is .... I work for a research firm based in Lomé -Togo, named CASE-AFRICA. Currently we are conducting a study on energy efficiency in your neighbourhood. Could you give me some time to answer a few questions? I assure you of the anonymous and confidential treatment of the information that will be collected.

Code of the questionnaire	
Number of households in the house	

R1. First, tell me how many households are currently in your home. i.e. of different groups of people who live under the same roof and who share the same meal.

House number selected	
If there is a substitution, specify the substitution number	

Use the household selection grid to select the appropriate household

<u>INFORMATION ON THE COUNTER</u>

Q1: Counter number: ....

Q2: Type of meter: 1. Single-phase 2. Three-phase 3. Additional 4. Sub-meter 5. Cash Power

Q3: Type of use :1. Domestic 2. Office, Business 3. Industrial

Q4: Current of the meter: 1. 10A 2. 30A 3. 60A

Q5: Meter power:

INFORMATION ON YOUR ELECTRIC CONSUMPTION

Q6: What were your electrical consumptions in the past three months?

	April 17	May 17	Jun 17
Consumption (KWH)			
Duration of consumption (days)			

INFORMATION ON THE POSSESSION OF ELECTRICAL APPLIANCES

Q7: What types of light bulbs do you use in your household?

Q8: how many bulbs of type ....

Q9: What is the rated voltage of these bulbs?

Q10: What is the rated power of these bulbs?
Q11: On average how many hours a day do you keep these lamps on?

Types of bulbs	Q7	Q8	Q9 (volt)	Q10 (watt)	Q11(hour)
Neon	1				
Fluorescent	2				
Led	3				
Incandescent	4				
Other specify					

Q12: Which television brands do you use in your household?

Q13: how many brand-name televisions ....

Q14: Were the TVs purchased new or used?

Q15: How many years have you used it since you bought it?

Q16: What is the rated voltage of these televisions?

Q17: What is the rated power of these televisions?

Q18: On average, how many hours a day do you keep these televisions on?

Brands of Televisions	Q12	Q13	Q14		Q15 (year)	Q16 (volt)	Q17 (watt)	Q18(hour)
LG	1		New Second hand	1 2				
SAMSUNG	2		New Second hand	1 2				
PHILIPPS	3		New Second hand	1 2				
SONY	4		New Second hand	1 2				
PRESIDENT	5		New Second hand	1 2				
GRUDING	6		New Second hand	1 2				
NASCO	7		New Second hand	1 2				
Other specify ____________________	8		New Second hand	1 2				

Q19: What brands of air conditioners do you use in your household?

Q20: How many branded air conditioners ....

Q21: Have the air conditioners been purchased new or used?

Q22: How many years have you used it since you bought it?

Q23: What is the rated voltage of these air conditioners?

Q24: What is the rated power of these air conditioners?

Q25: On average, how many hours a day do you keep these air conditioners on?

Air Conditioning Brands	Q19	Q20	Q21		Q22 (year)	Q23 (volt)	Q24 (watt)	Q25(hour)
LG	1		New Second hand	1 2				
SAMSUNG	2		New Second hand	1 2				
PHYLIPPS	3		New Second hand	1 2				
SONY	4		New Second hand	1 2				
PRESIDENT	5		New	1				

		Second hand	2
ROYAL AIR	6	New	1
		Second hand	2
NASCO	7	New	1
		Second hand	2
Other specify	8	New	1
		Second hand	2

Q26: What brands of brewers do you use in your household?

Q27: how many brand brewers ....

Q28: Have brewers been purchased new or used?

Q29: How many years have you used it since you bought it?

Q30: What is the rated voltage of these brewers?

Q31: What is the rated power of these brewers?

Q32: On average, how many hours a day do you keep these brewers on?

Brewing Brands	Q26	Q27	Q28		Q29 (years)	Q30 (volt)	Q31 (watt)	Q32(hour)
BINATONE	1		New	1				
			Second hand	2				
BRUDER	2		New	1				
			Second hand	2				
PRESIDENT	3		New	1				
			Second hand	2				
Other specify	7		New	1				
			Second hand	2				

Q33: What brands of living room fans do you use in your household?

Q34: How many show fans are branded ....

Q35: Have the salon fans been purchased new or used?

Q36: How many years have you used it since you bought it?

Q37: What is the rated voltage of these salon fans?

Q38: What is the rated power of these salon fans?

Q39: On average, how many hours a day do you keep these living room fans on?

Ventilator Brands	Q33	Q34	Q35		Q36 (year)	Q37 (volt)	Q38 (watt)	Q39(hour)
BINATONE	1		New	1				
			Second hand	2				
BRUDER	2		New	1				
			Second hand	2				
PRESIDENT	3		New	1				
			Second hand	2				
Other specify	7		New	1				
			Second hand	2				

Q40: What brands of freezers do you use in your household?

Q41: How many branded freezers ....

Q42: Have the freezers been purchased new or used?

Q43: How many years have you used it since you bought it?

Q44: What is the rated voltage of these freezers?

Q45: What is the rated power of these freezers?

Q46: On average, how many hours a day do you keep these freezers on?

Freezers brands	Q40	Q41	Q42		Q43 (year)	Q44 (volt)	Q45 (watt)	Q46(hour)
LG	1		New	1				
			Second hand	2				
BEKO	2		New	1				
			Second hand	2				
NASCO	3		New	1				
			Second hand	2				
Other specify	7		New	1				
			Second hand	2				

Q47: What brands of refrigerators do you use in your household?

Q48: how many branded refrigerators ....

Q49: Were the refrigerators purchased new or used?

Q50: How many years have you used it since you bought it?

Q51: What is the rated voltage of these refrigerators?

Q52: What is the rated power of these refrigerators?

Q53: On average, how many hours a day do you keep these refrigerators on?

Refrigerator brands	Q47	Q48	Q49		Q50 (year)	Q51 (volt)	Q52 (watt)	Q53(hour)
LG	1		New	1				
			Second hand	2				
BEKO	2		New	1				
			Second hand	2				
NASCO	3		New	1				
			Second hand	2				
Other specify	7		New	1				

Q54: What brands of electric cookers do you use in your household?

Q55: how many electric cookers are branded ....

Q56: Electric cookers were purchased new or used?

Q57: How many years have you used it since you bought it?

Q58: What is the rated voltage of these electric ranges?

Q59: What is the rated power of these electric ranges?

Q60: On average, how many hours a day do you keep these electric cookers on?

Electric stove or cooker	Q54	Q55	Q56	Q57 (year)	Q58 (volt)	Q59 (watt)	Q60(hour)
LG	1		New Second hand				
BEKO	2		New Second hand				
NASCO	3		New Second hand				
Other specify	7		New				

REBOUND EFFECT

QR1: If at the end of this study, it has been asked and authorized only efficient appliances that consume less electricity, would you buy other appliances?

Yes	☐
No	☐

QR2: If so, which appliances will you buy? Many possible responses

Appliances	
TV	1
Fridge	2
Freezer	3
air-conditioner	4
Fan	5
Brewer	6
Electric cooker	7
Other specify	8

GEOLOCATION POSITION
LONTITUDE
LONGITUDE
DESCRIPTION OF LOCATION
HOUSE

INTERVIEWER: thank the respondent and sign your interview, read the declaration below and approve by your signature.

I declare that this interview was conducted by me in person taking into account the instructions of a face-to-face interview with a respondent who was selected according to the sampling instructions.

Signature & date____

LAST NAME FIRST NAME ____